STABILIZATION OF BLACK COTTON SOIL WITH LOCUST BEAN WASTE ASH

By

AKINMADE, OLUSEGUN BABALOLA
B.ENG. (CIVIL),(BENIN 1986)
M.Sc/ENG/58679/2005 - 2006

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING.

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

SEPTEMBER 2008

DECLARATION

I hereby declare that this thesis is my research at Ahmadu Bello University, Samaru, Zaria. It has not been accepted in any previous application for a higher degree. All sources of information have been fully acknowledged in the references.

……. ……..

Akinmade, Olusegun Babalola Date

M.SC./ENG/58679/2005-06

CERTIFICATION

This Thesis entitled **"Stabilization of Black Cotton Soil with Locust Bean Waste Ash"** by Akinmade, Olusegun B. meets the regulation governing the award of the degree of Master of Science of Ahmadu Bello University and approved for its contribution to knowledge and literary presentation.

…… …….
Prof. K. J. Osinubi Date
Chairman Supervisory Committee

……. ……..
Dr. S. P. Ejeh Date
Head of Department

…… .....……
Prof. S. Nkom
Dean, Postgraduate School Date

DEDICATION

I dedicate this work to Almighty God for His privilege and grace given to me to be alive today. I give Him glory for making it possible for me to reach this stage of finishing this research work in good health.

ACKNOWLEDGEMENTS

My profound gratitude goes to my supervisor Prof. K .J Osinubi for his motivation, encouragement, valuable advices and unreserved commitment to bring this thesis to a logical conclusion. I am also grateful to the Head of Department of Civil Engineering, Dr. S. P Ejeh and Dr. O. S. Abejide for their useful encouragement during the conduct of this research work. I will also like to thank Engr. A. O. Eberemu whose advices, valuable suggestions and easy accessibility at all levels of this work were very valuable. My thanks also go to Engr. T S. Ijimdiya of the Department of Civil Engineering and all my colleagues, for the support they offered at a point in time.

This work will not be completed without making mention of the contributions of Mr. Cosmos Ejamah, Soil Mechanics Laboratory, Ahmadu Bello University, Zaria, Mr. Ishaya Ghandi of National Institute for Chemical Technology, Zaria, Mr. Abiodun Adesina who assisted greatly in collecting the locust bean waste ash from villages around Kaduna and Mr. Ernest Asemota who assisted in typing the manuscript. Furthermore, I cannot afford to leave out my 'one and only' Janet Oluwatoyin Akinmade, thank you for your support and encouragement. May the good Lord uplift you.

Finally, I want to express my warm and heartfelt thanks to all the members of my family and church for their support in one way or the other, The Lord reward you and grant you all your hearts' desires.

TABLE OF CONTENTS

CONTENT **PAGE**

Title ……..... i
Declaration ……..... ii
Certification…… …… iii
Dedication……... iv
Acknowledgments……..... v
Table of Contents ……. …… vi
List of Plates…….. x
List of Tables…….. xi
List of Figures…… xii
Appendix…… xiii
Abbreviations …….. xvi
Abstract…… xvii

CHAPTER ONE: INTRODUCTION 1

1.1 Preamble……. 1
1.2 Problem Statement ……. 3
1.3 Research Aim and Objectives……..... 5
1.4 Justification…… 6
1.5 Scope of Research…… 7

CHAPTER TWO: LITERATURE REVIEW 8
2.1 Origin of Black Cotton Soil…… …… 8
2.2 Engineering Properties of Tropical Black Clays……. …… 11
2.3 Clay Mineralogy and Chemical Composition of Black Cotton Soil…… 14
2.4 Heaving of Expansive Soils…….. 16
2.5 Conditions for Design of Highway Pavements……. 17
2.6 Techniques of Soil Stabilization…… ……... 17
2.6.1 Mechanical stabilization …….. 19
2.6.2 Chemical Stabilization……. 19
2.6.2.1 Stabilization with Cement…… … 20
2.6.2.2 Lime Stabilization …..…… 21

2.6.2.3 Stabilization with Phosphates…… . 22
2.6.2.4 Stabilization with Bituminous Material…… 23

2.7 Pozzolana …… 24

2.7.1 Properties of Pozzolana…….. 24

2.7.2 Fineness of Pozzolana …… 26

2.7.3 Use of Pozzolana in Soil Improvement…….. 26

CHAPTER THREE: **MATERIALS, METHODS AND RESULTS** 28
3.1 Materials ……. 28

3.1.1 Collection and Ashing of Locust Bean waste……... 28

3.1.2 Location and Mineralogy of Black Cotton Soil …… 29
3.2 Methods …… 30
3.2.1 Natural Moisture Content …… 31
3.2.2 Specific Gravity …… 32
3.2.3 Particle Size Distribution ……. 32
3.2.4 Hydrometer Analysis …… 33
3.2.5 Atterberg limits …… 34
3.2.5.1 Liquid Limit …….. 34
3.2.5.2 Plastic Limit …….. 35
3.2.5.3 Linear Shrinkage …… 36
3.2.6 Determination of pH of Natural and Stabilized Soils…… 36

3.2.7 Potential Volume Change ……. 37

3.2.7.1 Preparation of Test Specimens…… 37

3.2.8 Compaction …….. 38
3.2.8.1 British Standard Light …….. 38
3.2.8.2 West African Standard …….. 39
3.2.8.3 British Standard Heavy…….. …… 40
3.2.9 Unconfined Compression…… 41
3.2.10 Durability (durability test) …… 42
3.2.11 California Bearing Ratio……. 43

CHAPTER FOUR: DISCUSSION OF RESULTS 45
4.1 Preliminary Tests …… 45
4.2 Cement Rating of Locust Bean Waste Ash…… 48
4.3 Effect of Locust Bean Waste Ash on Particle Size Distribution …… 50
4.4 Evaluation of the Effect of Locust Bean Waste Ash on the

properties of Black Cotton Soil…… 51
4.4.1 Atterberg Limits …… 51

4.5 Compaction Characteristics …… 54

4.5.1 Maximum Dry Density …… 54
4.5.2 Optimum Moisture Content …… 56
4.6 Effect of Locust Bean Waste Ash on pH of Black Cotton Soil……. 57

4.7 Potential Volume Change ……. 59
4.8 Unconfined Compressive Strength…….. 60
4.8.1 Unconfined Compressive Strength for 7 days Curing Period…… 60
4.8.2 Unconfined Compressive Strength for 14 days Curing Period ……. 62
4.8.3 Unconfined Compressive strength for 28 days Curing Period ……. 63
4.8.4 Unconfined Compressive Strength for 7 days (waxed cured) and 7 days (soaked) Curing Period…… 65
4.9 Durability of Locust Bean Waste Ash Stabilized Black Cotton Soil….. 66
4.9.1 Effect of Curing Period on Locust Bean Waste Ash Stabilized Black Cotton Soil ……. 67
4.9.2 Effect of Immersion in Water on the Strength of Locust Bean Waste Ash Stabilized Black Cotton Soil…… 69
4.10 California Bearing Ratio …….. 70

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATION **1**01

5.1 Conclusions …… 72
5.2 Recommendation ……. 74

References …….. 76
Appendix A …….. 84
Appendix B …… 115

LIST OF PLATES

Plate 1: Cracks on a Pavement Built on Black Cotton Soil

Plate 2: Horizontal Cracks on a Building Built on Black Cotton Soil

LIST OF TABLES

Table 2.1 Comparison of Properties of Black Cotton Soils

Table 2.2 Properties of Pozzolanas

Table 3.1 Oxide Composition of Locust Bean Waste ash and Ordinary Portland Cement

Table 3.2 Oxide Composition of the Black Cotton Soil

Table 4.1 Geotechnical Properties of the Natural Black Cotton Soil

Table 4.2 Calculated Compound Composition of Locust Bean Waste Ash and Typical Ordinary Portland Cement

LIST OF FIGURES

Fig. 4.1 Particle Size Distribution Curve of Natural Black Cotton Soil

Fig. 4.2 Particle Size Distribution Curves of Locust Bean Waste Ash Treated Black Cotton Soil

Fig. 4.3 Variation of Atterberg Limits with Locust Bean Waste Ash Content

Fig.4.4 Variation of Maximum Dry Density with Locust Bean Waste Ash content

Fig.4.5 Variation of Optimum Moisture Content with Locust Bean Waste Ash Content

Fig.4.6 Variation of pH with Locust Bean Waste Ash Content

Fig.4.7 Variation of Swelling Pressure with Locust Bean Waste Ash Content

Fig.4.8 Variation of UCS with Locust Bean Waste Ash Content (7 days curing)

Fig.4.9 Variation of UCS with Locust Bean Waste Ash Content (14 days curing)

Fig.4.10 Variation of UCS with Locust Bean Waste Ash Content (28 days curing)

Fig.4.11 Variation of UCS with Locust Bean Waste Ash Content (7 days wax-curing and 7 days soaking)

Fig.4.12 Variation of UCS with Curing Period

Fig.4.13 Variation of Resistance to Loss in Strength with Locust Bean Waste Ash Content

Fig.4.14 Variation of CBR with Locust Bean Waste Ash Content

LIST OF APPENDICES

(i). Appendix A : Tables showing Test Results

Table 1 Natural Moisture Content Test Result

Table 2 Test Result of Specific Gravity of the Soil Particles

Table 3 Test Result of Specific Gravity of Locust Bean Waste Ash

Table 4 Sieve Analysis Result for the Natural Soil (0 % LBWA)

Table 5 Sieve Analysis Result for the Stabilized Soil (2.5 % LBWA)

Table 6 Sieve Analysis Result for the Stabilized Soil (5.0 % LBWA)

Table 7 Sieve Analysis Result for the Stabilized Soil (7.5 % LBWA)

Table8 Sieve Analysis Result for the Stabilized Soil (10 % LBWA)

Table 9 Sieve Analysis Result for the Stabilized Soil (12.5 % LBWA)

Table 10 Sieve Analysis Result for the Stabilized Soil (15 % LBWA)

Table 11 Result of Hydrometer Analysis for Natural Soil (0 % LBWA)

Table 12 Result of Hydrometer Analysis for 2.5 % LBWA Stabilized Soil

Table 13 Result of Hydrometer Analysis for 5 % LBWA Stabilized Soil

Table 14 Result of Hydrometer Analysis for 7.5 % LBWA Stabilized Soil

Table 15 Result of Hydrometer Analysis for 10 % LBWA Stabilized Soil

Table 16 Result of Hydrometer Analysis for 12.5 % LBWA Stabilized Soil

Table 17 Result of Hydrometer Analysis for 15 % LBWA Stabilized Soil

Table 18 Effect of Locust Bean Waste Ash on the Atterberg Limits of Black Cotton Soil.

Table 19 Effect of Locust Bean Waste Ash Content on pH of Treated Soil

Table 20 Effect of Locust Bean Waste Ash on the Swelling Pressures of Black Cotton Soil.

Table 21 Effect of Locust Bean Waste Ash on the Maximum Dry Density of Black Cotton Soil

Table 22 Effect of Locust Bean Waste Ash on Optimum Moisture Content

Table 23 Effect of Locust Bean Waste Ash Content on UCS (BSL Compactive Effort)

Table 24 Effect of Locust Bean Waste Ash Content on UCS (WAS Compactive Effort)

Table 25 Effect of Locust Bean Waste Ash Content (BSH Compactive Effort)

Table 26 Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (7 days UCS)

Table 27 Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (14 days UCS).

Table 28 Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (28 days UCS).
Table 29 Effect of Curing Period on UCS
Table 30 Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (BSL Compaction)
Table 31 Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (WAS Compaction)
Table 32 Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (BSH Compaction)
Table 33 Effect of Locust Bean Waste Ash Content on CBR (Unsoaked)
Table 34 Effect of Locust Bean Waste Ash Content on CBR (24 hours soaking)

(ii). Appendix B : Dry Density Versus Moisture Content Curves

LIST OF ABBREVIATIONS

OMC	Optimum Moisture Content
MDD	Maximum Dry Density
BSL	British Standard Light
WAS	West African Standard
BSH	British Standard Heavy
CSH	Calcium Silicate Hydrate
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
CBR	California Bearing Ratio
ASTM	American Society for Testing and Materials.
LBWA	Locust Bean Waste Ash

ABSTRACT

An expansive black cotton soil taken from a borrow pit located along Numan – Ngurore road in the North Eastern part of Nigeria was treated with an agricultural waste

ash produced from the burning of the husks of ripe fruits of the African Locust Bean tree that are abundantly available in Nigeria. The soil was classified as A-7-6 and CH in accordance with the AASHTO Soil Classification and Unified Soil Classification System (USCS), respectively. The study focused on the effect of up to 15% locust bean waste ash (LBWA) by weight of dry soil on the geotechnical properties of expansive black cotton soil. Test specimens were subjected to particle size analysis, compaction, unconfined compressive strength (UCS), California bearing ratio (CBR) and durability tests. The compactions were carried out at the energy levels of the British Standard Light (BSL),West African Standard (WAS) and British Standard heavy (BSH).

The maximum dry density values of 1.59, 1.68 and 1.8 Mg/m^3 obtained for the natural soil when compacted at the three energy levels of the BSL,WAS and BSH, respectively, increased to peak values 1.7, 1.72 and 1.8 Mg/m^3, respectively, on treatment with 7.5% locust bean waste ash content.

The optimum moisture content values of 18.53, 16.83 and 14% recorded for the natural soil when compacted at the three energy levels of the BSL. WAS and BSH, respectively, decreased to minimum values of 17.7, 16.6 and 13.7%, respectively, on treatment with 5 to 7.5% locust bean waste ash content. This trend is good in the tropics as less moisture is needed to achieve high compaction.

The CBR values of 3, 6 and 8% for the natural soil compacted at the energy levels of the BSL, WAS and BSH slightly increased to peak values of 6, 8 and 12%, respectively when treated with 7.5% locust bean waste ash. The peak CBR value of 12% recorded for the treated soil using the BSH compactive effort does not meet the minimum requirement of 15% prescribed by the Nigerian General Specification (1997)

for subgrade materials compacted at the BSL energy level.

The unconfined compressive strength (UCS) values for BSL, WAS and BSH compactive efforts obtained for the natural soil at 7 days curing period were 114.65 299.96 and 401.50 kN/m^2, respectively. For the same curing period the UCS values of the treated soil increased to 321, 325.15 and 384.5 kN/m^2 for the three compaction energies, respectively, at 7.5% locust bean waste ash content.

Considering the strength values recorded at an optimal 7.5% locust bean waste ash treatment of deficient black cotton soil, the LBWA cannot be used as a 'stand alone' stabilizer.

CHAPTER ONE

INTRODUCTION

1.2 Preamble

Generally in any engineering work, it is necessary for an infrastructure to be constructed with good and sound material so as to comply with the approved drawings, specifications and also to give financial advantage to the contractor on the project. In order to achieve these aims (as in road construction), it is necessary for such structures to be of adequate strength right from their foundation so as to reduce the rate of collapse of structures as it is being experienced in the nation presently. This is the main reason why the adequate knowledge of the properties of the foundation material (i.e., soil) should be readily available to the engineer

The black cotton soil is an expansive soil, characterized by excessive volume changes, expansive tendencies and low bearing capacities when wet (Chen, 1988; Nelson and Miller, 1992; Warren and Kirby, 2004). These soils have very high clay content and are prone to expansion when wet and shrinkage when dry. Thus because of this shortcoming, there is a need to improve the properties of this soil.

The above stated properties of black cotton soil affect the performance of pavement built over such formations. This is because the index properties of this soil show a sub-standard classification and its inadequacy for use as sub-grade material. In the north eastern part of Nigeria where this soil is predominant, it covers an extensive area such that avoiding it or finding a suitable replacement is not feasible. As a means of improving the geotechnical properties of black cotton soils, lime and cement have been

used as stabilizing agents. It is on record (Ola, 1983, Balogun, 1990, Osinubi, 1995, 1999, Osinubi and Medubi, 1997b) that appreciable improvements in the geotechnical properties of black cotton soils were observed when treated with lime and lime admixed with cement. Although the properties of this material are significantly improved, the implementation cost as a stabilizer is quite expensive. It is the cost implication that has aroused the thinking of research engineers to focus more on the use of potentially cost effective materials that are locally available to improve the properties of deficient soils (Osinubi, 1998, 1999, Osinubi and Medubi 1997a).

It is commonly accepted today in soil improvement work to examine the effects of local materials considered

to be wastes or residues which actually do not connote worthless substances as they may be economically viable for construction purposes (Osinubi, 2000a).

One of the local materials to be considered is the ash obtained from the combustion of the waste from locust bean. It has three components namely: the seed commonly used to produce local seasoning for food, the powder and husk.

Out of these components, the waste product is the husk which when burnt in an open place will eventually result in locust bean waste ash (LBWA).

The locust bean tree is common in our environment and it grows to about 15 m in height and has dark, evergreen, pinnate leaves. The small, red flowers have no petals. The fruit is a brown, leathery pod about 10 to 30 cm long and contains gummy pulp of an agreeable sweet taste, in which lie a number of seeds. The seeds are edible but the

waste products litter our communities with corresponding negative environmental impact. The treatment of the soil with the locust bean waste ash could be a viable way of ameliorating this social menace.

1.3 Problem Statement

Although nature has endowed different parts of the country with soils suitable for highway construction, the north-eastern part has a large expanse presence of the problematic expansive black cotton soil which is characteristic of impeded drainage sites. These expansive soils belong to the smectite group, which includes montmorillonite that is highly expansive and are the most troublesome clay minerals when encountered in construction. Primarily, the problem that is associated with regard to expansive soils is that their deformations are significantly greater than the elastic deformations and therefore cannot be predicted by classical plastic or elastic theory. Movement is usually in an uneven pattern and of such a magnitude as to cause damage to the structures and pavements resting on them (Nelson and Miller, 1992).

In northeastern Nigeria where black cotton soils are predominant, and wherever they exist in the world, they cannot meet the strength and compressibility requirements imposed by their use in sub-grades. Normally, the first step in alleviating a problem is to identify the problem and understand the preventive measures that are available. The next step, which is very essential, is to provide careful, responsible engineering and construction. Research then becomes inevitable as it provides knowledge and data for input into understanding of phenomena and design. It is therefore a welcome development to be aware of the existence of expansive soils and their locations. As a

result, more problems are diagnosed correctly, whereas in earlier years many expansive soil problems were incorrectly attributed to heave/ settlement (Morin,1971).

Expansive soils cause more damage to structures, particularly light buildings and pavements than any other natural hazard, including earthquakes and floods (Jones and Holtz, 1973). Although the estimation of damage especially in Nigeria is inexact and somewhat subjective, even the most conservative estimates show that expansive soils are a major contributor to the burden that natural hazards place on the economy (see Plates 1 and 2) for cracks in collapsing road pavement and residential building built on the soil along Numan – Ngurore road).



Plate 1: Cracks on a pavement built on black cotton soil



Plate 2: Horizontal cracks on a building built on black cotton soil

1.3 Research Aim and Objectives

The aim of the research was to investigate the feasibility of using locust bean waste ash to stabilize black cotton soil. The work sought to achieve the above aim through the following objectives:

a. Evaluation of the effect of locust bean waste ash on the index and engineering properties of stabilized black cotton soil.

b. Evaluation of the effect of locust bean waste ash on the swell/shrink tendencies of the stabilized black cotton soil.

c. Determination of the optimum amount of locust bean waste ash required for the stabilization of the black cotton soil.

d. Verification of the resultant strength values obtained at the optimum percentages of the stabilizer whether they meet the specification for pavement construction.

e. Determination of the effect of the various compactive energies, British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) on the locust bean waste ash treated black cotton soil as well as their unconfined compressive strength (UCS) and California bearing ratio(CBR).

1.4 Justification

Stabilization is aimed at improving the strength and durability of a soil. A great number of substances have been used for soil stabilization and much research is going on to find the most suitable stabilizer for each soil type. Despite these research efforts, there is yet no "MIRACLE" stabilizer that can be used in all cases.

Although a lot of research has been carried out on black cotton soil using stabilizers such as lime, cement and bitumen to improve the strength properties in the past (Ola, 1983) ,stabilizing this soil with locust bean waste ash has received very little attention. However, an attempt was made to stabilize lateritic soilcrete building blocks with the extract obtained from the husks of the ripe fruit of locust bean tree which is in the organic form (Mohammed, 1997; Akolo, 2000). In contrast, this research work

made use of burnt waste ash as a pozzolana thus aiding the improvement of the soil properties.

In addition, the application of lime, ordinary Portland cement and bitumen as stabilizers have improved the engineering properties of soils. Nevertheless, the rising cost of these additives is a burden and locust bean waste ash may be relatively cheaper and available. So the stabilization of expansive black cotton soil with the locust bean waste ash (LBWA) if found suitable economically would make available an abundance of road making material for the construction industry.

Consequently, the study was undertaken to find a working solution to the problems created by expansive black cotton soil by treating it with locust bean waste ash (LBWA).

1.5 Scope of Research

The research was limited to finding the engineering properties of stabilized black cotton soil when used to build a highway under unavoidable environmental conditions (e.g. access to excessive moisture content).The oxide compositions of the locust bean waste ash and the percentage which produced an economic design for the stabilization of black cotton soil if used for fill material (i.e., to sustain the anticipated traffic load without deformation) in line with the Nigerian General Specification (1997) as well as AASHTO (1986) and ASTM (1992) requirements for transportation materials were determined.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of Black Cotton Soil

Tropical black clay otherwise known as Canada's swelling clays, India's black cotton soil and Kenya black cotton soils can be found all over the world (Chen, 1988). Warren and Kirby (2004) refer to black cotton soils as "swelling soils" "heaving soils" and "volume change" soils. Sahel (1993) describes expansive clay formations as being favoured by the geology, climatic condition and the environment of extreme disintegration, strong hydration and restrained leaching. Expansive soils swell and shrink considerably with changes in moisture content. Due to the problems associated with these soils, road and building construction on this type of soil demand special knowledge which is in the hands of relatively small group of experts (Ibrahim, 1977). An engineering definition of these soils is "a dark grey or black soil with a high content of clay usually over 50% in which montmorrilonite is the clay mineral and which are commonly expansive"(Morin,1971).

Tropical black clays are formed residually by weathering (Morin, 1971). Two groups of parent rock materials have been associated with the formation of expansive soils. The first group comprises sedimentary rock of volcanic origin, which can be found in North America, South Africa and Israel (Ola, 1978), while the second group of parent materials are basic igneous rocks found in India, Nigeria and South western U.S.A (Plait, 1953).

Expansive soils are seen mostly as tropical black clay soils also known as black cotton soils in Africa (Morin, 1971). They are found in the northeastern parts of Nigeria, Cameroon, Lake Chad Basin, Sudan, Ethiopia, Kenya, South Zimbabwe and other Eastern African Countries. They are also found in India, Australia, South Western U.S.A (Tomlinson, 1999), South Africa and Israel (Ola, 1978).

Black cotton soils are black clays that are produced from the breakdown of basic igneous rocks, where seasonal variation of weather is extreme. Specifically, Nigerian black cotton soils are formed from the weathering of shaly and clayey sediments and basaltic rocks. According to Ola (1983) ,the Nigerian black cotton soils contain more of the montmorillonite with subsequent manifestation of swelling properties and expansive tendencies.

Black cotton soils are types of expansive soils which pose major problems to roads constructed over them due to their high volume changes, severe cracking when dry, low bearing – values when wet and lack of drainage. These soils are formed in regions subject to distinct wet and dry seasons, alternate upward and downward movement of water aiding the concentration of iron or alumina. The climatic condition is such that the annual evaporation exceeds the precipitation (Chen, 1988). The word "tropical" is included, in the name of the soil because the tropical climate favours the formation of this type of soils (Agboola, 1991).

Frequently associated with the reddish soils of the tropics are very dark coloured soils often called black cotton soils. The dark colour of these soils is seldom due to organic accumulation but rather to the presence of iron, manganese and titanium compounds in the reduced state. These soils are apparently formed under conditions of

poor drainage from basic rocks or sometimes limestone under alternating wet or dry climatic conditions. They usually show high shrink-swell characteristics with surface cracks, opening during the dry seasons which are more than 50 mm or more wide. The cracks close during the wet season and uneven soil surface is produced by irregular swelling and heaving. Such soils are especially troublesome as pavement sub-grades or under shallow foundations. The amount of potential volume change is dependent on the mineralogical composition and clay mineral types. This means that the soils which contain more montmorillonite have higher potential volume change than those that have less of the mineral (Ola,1983).

Some of the major roads that link Nigeria with the neighbouring republics of Cameroon and Chad pass through these problematic soils. These roads carry Nigeria's exports of fuel and other produce which approached some 250,000 tonnes per annum from the main Nigerian ports through Kano and Maiduguri to these neighbouring countries (Ibrahim 1977). The problem of road construction on these soils is further complicated by the fact that about 75% of the commercial vehicles travelling out of Nigeria are overloaded. Also, most of the vehicles transporting fuel to the neighbouring countries often have axle loads in excess of 14 tonnes and some axle loads are heavier than 20 tonnes(Ola,1983).

2.2 Engineering Properties of Tropical Black Clays

The most common identifiable characteristics among the tropical black clays are high clay content in which montmorillonite is the principal mineral. The soils are commonly expansive, dark coloured, having the tendency to expand and shrink with change in moisture as well as having appreciable plasticity in the clay fraction.

From an extensive research by Morin (1971), the properties of African tropical black clay soil can be summarized as shown in Table 2.1 Results of studies carried out by Osinubi (1995, 1999) on samples of black cotton soils taken from the New Marte areas of Borno State, Nigeria and Plait (1953) on Indian black cotton soil, the following geotechnical properties of the soil which are in agreement with Morin (1971) are also summarized in Table 2.1.

Table 2.1 : Comparison of Properties of Black Cotton Soils

PROPERTY	AFRICA*	NIGERIA**	INDIA***
Gravel content, %	-	-	2.4
Sand content, %	4 - 41	10-22	11.8
Clay content, %	40 - 70	71	65.8
Liquid limit, %	22 – 109	62.3	96.5
Plastic limit, %	14 – 42	24.2	40.4
Plasticity Index, %	8 – 81	38.1	56.1
AASHTO Classification	A-7-5 to A-7-6	A-7-6	A-7-6
Group Index	13 – 89	24	-
Free Swell, %	50 – 100	76.25	-
pH	6.3-9.2	7.7	-
California Bearing Ratio, %	0.8 – 1.6	3	2
Maximum Dry Density, Mg/m^3	1.37 – 1.92	1.71	-
Optimum Moisture Content, %	13.0 – 32.2	18.0	-
Specific gravity		2.4	2.7

*****Morin (1971)

**Osinubi (1995, 1999)

***Plait (1953)

Ola (1983) and NBRRI (1983) have reported that the black cotton soil of Nigeria have been laid during the late tertiary and quaternary periods as the Chad formations and are composed of a sequence of lacustrine and fluviatite clays and sands of Pleistocene age. According to Ola(1983), black cotton soils with montmorrilonite as the predominant clay mineral are the most troublesome soils in Africa. In Nigeria, they occupy an estimated area of 104,000km^2. The soil is so named because cotton plant thrives well on it. Usually, there is less or no presence of organic materials in the soil, but the black colour is probably due to iron or titanium (Jha and Sinha, 1993).

The geotechnical properties of the various samples of black cotton soils from the researches of Plait (1953), Morin (1971) and Osinubi, (1995, 1999) are consistent. Therefore, taking a close look at the geotechnical properties of the tropical black clay and examining its suitability for highway construction, it is important to compare the properties of this soil with the minimum design requirements as specified by Braja (1998) and the Nigerian General Specification (1997).

The group index (GI) is issued as a means of identifying the suitability of a soil for use as a sub-grade material. Generally, the lower the group index, the more suitable the soil is for use in sub-grade. From the results of studies presented above, it is seen that the black cotton soils with G.I. varying from 13 to 89 are generally not suitable for use as sub-grade materials.

The California bearing ratio (CBR) test is also another method of measuring the suitability of materials for use as highway construction materials. CBR testing procedures vary from region to region and according to the Nigerian General Specification (1997) for a material to be suitable for sub-grade construction, it must have

a minimum of 15 % CBR, while for sub-base the minimum CBR is 30 % and for base course, unsoaked CBR should not be less than 80 %. From the results of studies carried out by Plait (1953), Morin (1971) and Osinubi (1995, 1999), the maximum CBR value recorded for black cotton soil was 2 % which did not meet the minimum requirement for use as sub-grade.

The AASHTO classification for black cotton soil is normally A-7-5 to A-7-6. Soils within this classification are generally not good materials to employ for use in highway construction (Morin,1971).

2.3 Clay Mineralogy and Chemical Composition of Black Cotton Soil

Montmorillonite and kaolinite are the two predominant clay minerals found in black cotton soils. Black clays which are the most expansive soils contain more of the montmorillonite than kaolinite (Morin,1971;Osinubi and Medubi,1997a). The predominance of montmorillonite is due to the weathering of the basic constituents (Ola, 1983). Chen (1988) observes that clay mineral containing montmorillonite (a smectite) generally exhibits a swelling tendency in the presence of water.

The swell and shrink characteristics of the black cotton soils are largely due to montmorillonite while kaolinite is likely responsible for the high strength value because of its inability to swell with absorbed water. Montmorillonite clay structure is described as consisting of bonded sheets of one gibbsite or octahedral sheets (Octahedral units consisting of six hydroxyls surrounding an aluminium atom and the combination of the octahedral aluminium hydroxyl units gives an octahedral sheet) sandwiched between two silica sheets held by weak van der Waal forces (Bowles, 1979, Braja, 1998). The

instability of the montmorillonite structure induces the replacements of the silica in the tetrahedral with aluminium ions and replacement of aluminium in the octahedral unit with Mg, Fe, Li or Zn. This engenders a net charge disequilibrum (negative) resulting in the water absorbing tendencies, as there is an attraction for the H^+ ions in water.

On the other hand, kaolinite is a relatively inactive clay mineral with a structure made up of repeating layers of elemental silica-gibbsite sheets in a 1:1 lattice (Braja, 1998). Its inactivity is attributed to the presence of hydrogen and van der Waal's forces that give an overall unit of enhanced strength.

For black cotton soil to be used as a sub-grade material, there is need to improve its geotechnical properties. There are several methods for improving the properties of deficient soils, commonest among such methods is soil stabilization. Soil stabilization has been used in the construction of roads and aircraft runways, earth dams and embankments in erosion control (Kawamura and Diamond, 1975). Various stabilizers have been used to stabilize or improve the geotechnical properties of sub-grade soils and the commonest stabilizers used for this purpose in Nigeria are cement, lime and bitumen. (Ola, 1978; Osinubi, 1995, 1998b, 2000a; Osinubi and Bajeh. 1994). However, these materials have become so costly that inadequate quantities are applied than are required, hence defeating the aim. It is in this light that locally available and agricultural waste or industrial waste is sought for use as a replacement or supplement to costly imports.

2.4 Heaving of Expansive Soils

In the geotechnical engineering field, it has been long observed that the swelling of expansive clays caused by moisture changes may result in excessive heave and therefore in severe damage to overlying structure or pavements. The damage due to this soil is enormous and manifests in the following forms: cracking of mansonry fences, reinforced concrete gates and road pavements (Sahel, 1993).

Gromko (1974) describes the heaving of an expansive foundation soil to be in the following ways:

- A general upward movement beginning shortly after the start of the construction and finishing some years after the completion of the structure.
- A seasonal cyclic expansion-contraction, which normally occurs around the structure and is primarily related to the amount and frequency of rainfall and the rate of evaporation
- Local heaving, which may result from the breakage of water lines or poor site drainage.

The main factors involved in the heave phenomenon are:

- Soil type (including the proportion of clays and mineralogy)
- Dry density (and soil structure)
- Moisture content (which is related to suction for a given soil)
- Permeability (time to heave is a function of permeability)
- Thickness and depth of the expansive soil stratum
- In-situ stress condition (both vertical and horizontal)
- Externally applied loads (and appropriate stress path)

- Sources of moisture variation (climate, position and variation of water table, drainage leaks and vegetation).

2.5 Conditions for Design of Highway Pavements

Highway pavement designs involve the process of evaluating the type and thickness of various materials to be incorporated in the road pavement. A road pavement must provide a satisfactory ride to the road user and also must remain structurally sound to satisfy the engineer's design. It is worthy of note that road pavements do not fulfill their basic function especially when they run on expansive soils. The need to provide a structurally efficient highway facility to meet the specification for efficient road network in areas with these formations supersede whatever hindrance that is expected in improving the adverse behaviour of the soil.

Pavement design decision for both flexible and rigid pavement is based on functional failure rather than structural failure. Structural failure could include the collapse or breakdown of one or more of the pavement components (Yoder and Witczak, 1975). On the other hand, functional failure implies that the pavement does not function as it was intended, that is causing high stresses or vibrations in the vehicles passing over it. Functional failure depends on the level of surface roughness, which may or may not be accompanied by structural failure (Nelson and Miller, 1992)

2.6 Techniques of Soil Stabilization

Soil stabilization is a term applied to any process which improves the engineering properties of deficient soils and subsequently enables them to perform and sustain its

intended engineering use (Yoder and Witczak, 1975; Gilliot, 1987; Nicholas and Lester, 1999). Primarily, the objectives of stabilization are to improve soil strength, to decrease permeability and water absorption and to improve bearing capacity and durability under cyclical conditions such as varying moisture content. Soil stabilization with cement, lime and fly ash and the mechanism of stabilization are extensively covered in the studies earlier conducted in various parts of the world (Anessi, 1968, Kumar, 1974, Lagurous and Keshawarz. 1987).

Gromko (1974) states that one of the methods of expansive soil treatment for foundation is the excavation of the troublesome soil and this is not in agreement with Gilliot (1987) who observes than an unstable soil has to be removed and replaced with other foundation materials such as gravel or crushed rock, the cost is high owing to the weight and bulk of the materials involved.

Therefore, soil stabilization is an economic means of improving soils at the site of construction through the use of stabilizers. Stabilizers are the agents used to improve the engineering properties of soil, and stabilizers are used on soil when the soil does not possess the desired characteristics for a particular construction. The kind of stabilizer to be used depends on which properties of the soil are to be improved, the nature and type of the soil.

A great number of substances can be used for soil stabilization and much research is going on to find the most suitable stabilizers for each soil type and nature of its problem. Despite these research efforts, there is yet no “MIRACLE” stabilizer that can be used in all cases as stabilization is not an exact science.

Two methods of soil stabilization exist; these are:

i) mechanical and

ii) chemical

2.6.1 Mechanical stabilization

A soil structure is said to be mechanically stable when it can resist lateral displacement under load. A stable soil can be obtained through controlled grading of the coarse aggregate, fine aggregate, silt and clay correctly proportioned and fully compacted. The process of controlled grading is referred to as mechanical stabilization (Gilliot, 1987). Therefore, mechanical stabilization involves soil densification through the application of mechanical energy. Mechanical energy brings about the reduction of air void in the soil, with little or no reduction in water content. It also lowers the permeability of the soil material and an increase in dry density (Markwick, 1944).

2.6.2 Chemical stabilization

When inorganic and organic compounds are added to soils, their strengths, bearing capacities and durabilities increase (Gilliot, 1987). These chemical compounds primarily act as cementitious and binding agents or even water proofers.

Inorganic compounds employed include ordinary Portland cement, lime, slag, sodium silicate, phosphorous compounds and sometimes a combination of these (Gilliot, 1987; Nicholas and Lester, 1999; Yoder and Witczak, 1975; Osinubi, 1995; Osinubi and Medubi, 1997a).

Inorganic salts such as sodium chloride and calcium chloride have long been used in stabilization and their chief function is to reduce plasticity and facilitate densification (Yamanouchi, 1975; Habercom, 1976 ; Gilliot, 1987; Balogun, 1991).

2.6.2.1 Stabilization with cement

Stabilization of soils with cement usually involves the mixing of predetermined quantities of the additive with pulverized soil particles. The mixture is termed “soil-cement”. Cement improves the strength of most soils. The Portland Cement Association (1970) has indicated that nearly all types of soils can be stabilized with cement. In general, gravels require about 10 % by weight of cement, sand requires about 7 to10 %; silts about 12 to 15 % and clays about 12 to 20 % by weight of cement (Gilliot 1987). W hen soils are sandy, mixing of cement and soil can be carried out at or slightly above optimum moisture content but with clayey soils mixing is most readily achieved with moisture slightly below optimum.

Hydration is the first phase of the cement stabilization reaction. Cement hydration produces a cementitious compound which is a product of cement and water. It generates bonding between the reaction products (calcium silicate hydrates and aluminum hydrates) and the soil particles. This results in agglomeration and flocculation of the clay particles due to exchange of ions at the surface of the particles. These manifest an early strength development, immediate reduction in swell, shrinkage and plasticity. However, Portland cement is not effective as lime in stabilizing highly plastic clays. Some clay soils have such a high affinity for water that the cement may not hydrate sufficiently to

produce the complete pozzolanic reaction. It is usually advantageous to use cement when soils are not lime reactive (Nelson and Miller, 1992) it is therefore, essential that sufficient moisture be added for the cement hydration to go to completion.

Cement stabilization becomes uneconomical for soils with plastic limits greater than 20 or liquid limits in excess of about 45 to 50. However, heavy clays can be stabilized with cement by previously adding a small amount of lime which reduces the plasticity and makes the soil more workable; the soil with lime is allowed to age for one to three days and is then stabilized with cement. For soils which contain clay minerals in excess of 30 %, it becomes more difficult to achieve economical stabilization with cement due to greater difficulties in pulverizing and mixing. In general, the quantity of cement required for stabilization increases with the proportion of clay minerals in a soil (Gilliot, 1987).

Sulphates in concentration of 1 % or less and organic matter may have detrimental effect upon the stabilization of soils with cement (Gilliot, 1987). Concrete deterioration is known to result from attack by sulphate ions. The aggressive compounds also known as ettringite (calcium sulpho-aluminate; $3CaO\ Al_2O_3$, $3CaSO_4$, $3H_2O$) is formed as a result of the combination of tricalcium aluminate ($3CaO$, Al_2O_3), lime, water and sulphate ions.

2.6.2.2 Lime stabilization

In road construction, lime has been widely used for the stabilization of subgrade, sub-base and even base course improvement. It is important to mention here that the treatment of soil with lime up to about 3 - 4 % by weight of dry soil is basically soil

modification which is the improvement of physical properties of the soil in order to make it more workable.

Lime is generally not suitable for the stabilization of coarse soils but it is better for the treatment of clayey and silty soils. There is a sharp contrast between lime and cement stabilization. As more cement is added to soil, the strength gain is enhanced while for lime stabilization, excess lime may lower the soil strength by acting as low strength filler separating the mineral grains.

The primary reaction of lime-soil mixture includes cation exchange, flocculation-agglomeration, lime carbonation, and pozzolanic reaction. Factors influencing soil - lime reactivity are, (Nelson and Miller, 1992):

- A soil pH greater that 7 indicates good reactivity
- Organic carbon greatly retards soil-lime reactions
- Poorly drained soils tend to have higher lime reactivity than well drained soils
- Calcareous soils have good reactivity
- Sulphates and some ion compounds inhibit the lime reaction.

2.6.2.3 Stabilization with phosphates

Phosphoric acid has not been used to a great extent in soil stabilization. When phosphoric acid reacts with clay minerals, it is believed to release aluminum hydroxide. Various aluminum phosphates are believed to form and act as cementitious binder between the mineral particles of the soil. It is important to note that with phosphoric acid, the maximum strength development is not dependent on the optimum moisture

content used. In alkaline soils, such as those that contain calcium carbonate, the phosphoric acid stabilization has more promise for acid soils with high clay content.

In order to rid the environment of debilitating waste, studies were conducted to consider the economic utilization of a solid mineral waste resource - phosphatic waste. The properties of treated lateritic soils were marginally improved (Fakiyesi and Osinubi, 1995, 1996; Osinubi, 1997). Furthermore, investigations carried out in the laboratory to consider the use of the waste as an admixture in lime and cement stabilization of tropical black clay recorded improvements in the engineering properties of the deficient soils (Osinubi and Toro, 1996; 1997; Osinubi and Medubi, 1997a,b).

2.6.2.4 Stabilization with bituminous materials

Bitumen is a viscous liquid, or solid consisting essentially of hydrocarbons and their derivatives, which is soluble in carbon disulphide; it is substantially non-volatile and softens gradually when heated. It possesses both waterproofing and adhesive properties. Bituminous materials coat the soil and aggregate grains and retards or stop absorption of water. Bituminous soil stabilization has been most successfully employed in the stabilization of non-cohesive or mildly cohesive soils particularly in warm dry climates where the soil has low moisture content (Gilliot, 1987, Osinubi and Bajeh, 1994; Osinubi, 2000b, 2001b).

2.7 Pozzolana

The most commonly used additive for soil modification or stabilization is ordinary Portland cement (Chu and Kao, 1993; Hausmann, 1990). However the strength of cement treated soil can be improved by pozzolanic reactions.

Lea (1956) describes pozzolana as a material capable of reacting with lime in the presence of water at ordinary temperatures to produce cementitious compounds. Pozzolans are defined as siliceous and aluminous materials which themselves possess little or no cementitious value but will, in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Robert, 1993).

More recent development has shown the potentials of utilizing agricultural wastes for producing cementitious compounds in conjunction with lime. Many plants, during their growth pick up silica from the ground, into the structure of their leaves, stalks and other parts. Therefore, when such agricultural products are burnt, organic materials which are the largest proportion are broken down and disappear as carbon dioxide, and water vapour. The resulting ash consists mainly of inorganic residue, mostly silica. When silica is in its reactive form, it can combine with lime to form insoluble cementitious compounds (Smith, 1992).

2.7.1 Properties of pozzolana

ASTM C618-78 describes pozzolana as a siliceous and aluminous material that in themselves possess little or no cementitious value but, will in finely divided from and in the presence of moisture, chemically react with calcium hydroxide at ordinary

temperatures to form cementitious compounds. From this definition, it is clear that pozzolanas contain high percentages of silica. Other necessary oxides for a reactive pozzolanas are alumina and iron oxides. The in-situ is expected to be in amorphous state, which is more reactive than the crystalline silica. This is the basis for temperature regulation during the burning of agricultural waste (Mohamedbhai and Baguant, 1990). The ASTM ref C618 – 78 specifications for pozzolanas is given in the Table 2.1

Table 2.2: Properties of Pozzolanas (ASTM C618-78)

Property	**Class N**	**Class F**	**Class C**
Chemical Properties			
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	70	70	50
SO_3 (Max %)	4	5	5
MgO (Max %)	5	5	5
Loss on ignition	10	2	6
Physical Properties			
Moisture content (%)	3	3	3
Fineness (%) on sieve No. 200 (mm)	85	85	85
Pozzolanic Activity			
Index with OPC at 28 days (%)	75	75	75
Pozzolanic Activity Index with lime at 7 days	5.5	5.5	5.5

2.7.2 Fineness of pozzolanas

An essential physical property of a cementing material that affects its affinity for water is its fitness. The activity of pozzolanas are increased by fine grinding ASTM C618-78 specification requires that the percentage passing sieve No. 200 ≥ 85% (Lea, 1956, Smith, 1992).

2.7.3 Use of pozzolana in soil improvement

In order to minimise the high cost of soil improvement when conventional additives are used, geotechnical engineers (Cokca, 2001; Medjo and Riskowiski, 2004) have focused on pozzolanas for use as substitute or partial replacement for the standard stabilizers. A larger amount of these materials are obtained from agricultural wastes. When plant residues are burnt, organic materials which are the largest constituents are broken down and disappear as carbon dioxide, water vapour etc. The ash which remains contains mostly inorganic residue, notable silica in amorphous form which reacts with the oxides in the soil thus aiding the improvement of the soil properties.

Recent research in the Department of Civil Engineering, Ahmadu Bello University, Zaria, focused on the use of bagasse ash as possible stabilizer/admixture (Osinubi and Stephen, 2005; 2006a, b, 2007: Osinubi and Mustapha, 2005, 2008; Osinubi and Eberemu, 2006; Osinubi et al., 2007a,b,c; 2008a,b,c). Stephen (2005) studied the potential of bagasse ash as stabilizer on black cotton soil. A general improvement on the properties of the soil using bagasse ash as additive was reported.

The ash has also been used as admixture along with lime and cement in stabilizing black cotton soil (George, 2006; Osinubi et al., 2008a,b). This application will go a long way in reducing the total cost of stabilization and the potentials to use some quantities of the waste ash that have constituted an environmental problem.

CHAPTER THREE

MATERIALS, METHODS AND RESULTS

3.2 Materials

3.1.1 Collection and ashing of locust bean waste

The locust bean waste ash (LBWA) used for the study was obtained locally from the burning of locust bean husks sourced from villages (i.e. Sabon Gaya, Sabon Maro, Maraban Jos, Bishimi and Birnin Yero) around Kaduna city in Kaduna State. The husks of the locust bean generated through human activities were collected from dumps in these villages and stockpiled. Smith (1992) as well as Mohamedbhai and Baguant, (1990) reported that heat treatment plays a vital role in the production of viable and useful pozzolanas from agricultural wastes. Therefore, the stockpiled husks of the locust bean generated was burnt to ash in the open air within a temperature range from 500 to 700^{o}C (that was monitored using a thermocouple) on a galvanized roofing sheet platform in order to avoid contamination. The resulting ash obtained was allowed to cool before being passed through BS No. 200 sieve with 75 μm aperture to meet the requirements of Class N Pozzolanas (ASTM C 618 -78).

A comparison of the oxide composition of the LBWA used in the study obtained by X-ray fluorescence (XRF) analysis method with that of the ordinary Portland cement is given in Table 3.1.

Table 3.1 Oxide Composition of Locust Bean Waste ash and Ordinary Portland Cement

Oxide	**Locust Bean Waste Ash (%)**	***Ordinary Portland Cement (%)**
CaO	1.08	63
SiO_2	55.38	20
Al_2O_3	14.93	6
Fe_2O_3	0.278	3
MnO	0.09	-
Na_2O	0.18	1
K_2O	2.00	-
SO_3		2
P_2O_5	0.23	-
Loss on Ignition	10.63	2

*After Czernin, 1962

3.1.2 Location and mineralogy of black cotton soil

The soil sample used in this study was collected from a borrow pit located along Numan – Ngurore Road, Lamurde Local Government Area of Adamawa State. It was collected as a disturbed sample obtained at the depth of 1.0 m from the ground surface in order to avoid organic matter. Numan – Ngurore is situated between lat $12^o15'$, long $9^o30'$ and lat $12^o10'$,long $9^o25'$. The oxide composition of the black cotton soil

according to Stephen (2005) is summarized in Table 3.2. From extensive research works done by Ola (1983) and Osinubi (1995) on soil in this area, the predominant clay mineral in this soil is montmorillonite.

Table 3.2 Oxide Composition of the Black Cotton Soil

Oxide	**(%)**
CaO	-
SiO_2	31.01
Fe_2O_3	4.74
Al_2O_3	16.19
MnO	0.13
TiO_2	1.34
LOI ,Others	≤ 52

3.2 Methods

The laboratory tests performed on the soil in order to determine its engineering properties were in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and stabilized soils, respectively. The following tests were performed

1. Natural moisture content
2. Specific gravity
3. Particle size distribution

4. Hydrometer analysis
5. Liquid limit
6. Plastic limit
7. Linear shrinkage
8. pH
9. Potential volume change
10. Compaction (BSL, WAS, BSH), in order to determine the moisture- density relationships
11. Unconfined compression
12. California bearing ratio.

3.2.1 Natural moisture content

The natural moisture content was determined according to the specification of the Test 1 (A) of B.S 1377 (1990). Known weights of pulverized soil samples were weighed in a pre-weighed container. The measurements of the weight of the container and container plus soil were read to the nearest 0.1g. The samples were oven dried for 18 hours at 105^{o}C to 110^{o}C continuously.

The natural moisture content was determined from the expression:

$$W = \frac{M_2 - M_3}{M_3 - M_4} \times 100 \quad \text{.....(3.1)}$$

W = Moisture content (%)

M_2 = Weight of Container plus wet soil (g)

M_3 = Weight of Container plus dry soil (g)

M_4 = Weight of container (g)

The results of the test are summarized in Appendix A.

3.2.2 Specific gravity

In determining the specific gravity of the natural soil, Test 6(B) of B.S 1377 (1990) which is applicable to fine gained soils was adopted. Air dried samples of the soil were placed to fill a 50 ml density bottle, after weighing, water was added to the soil until it was topped with water. The container was then emptied and filled with water alone. The specific gravity was calculated as follows:

$$G_S = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (3.2)$$

Where,

G_s = Specific gravity

M_1 = Weight of density bottle (g)

M_2 = Weight of density bottle plus dry soil (g)

M_3 = Weight of bottle, soil and water (g)

M_4 = Weight of bottle and water only (g)

The results of the test carried out on the soil and locust bean waste ash are summarized respectively in Appendix A.

3.2.3 Particle size distribution

The particle size distribution of the natural soil was determined using both sedimentation analysis and dry sieving of the coarse fraction as specified by BS 1377 (1990) for cohesive soils. The soil sample was washed through BS sieve No. 200 and the

materials retained was oven dried and sieved by agitating the material through a range of sieves from sieves No.7 or 2.4 mm sieve and downwards while the material was turned into a sedimentation cylinder for hydrometer analysis for the natural and treated soils. See the results for the particle size distribution data of the natural soil and the stabilized soil at different ash percentages in Appendix A.

3.2.4 Hydrometer analysis

A density hydrometer No. 680102 was used to measure the density of the soil pretreated with sodium hexametaphosphate at various intervals of time, according to the procedures given in BS 1377(1990) and Head (1980). The hydrometer was calibrated and the calibration equation obtained as:

$$H_f = 17.67 - 0.176R \quad \text{(3.3)}$$

Cm = 0.2; meniscus correction used.
Where R= hydrometer reading

The particle diameter, D (mm) for each reading was obtained from the expression:

$$D = k\sqrt{Hr/t}\ (mm) \quad \text{(3.4)}$$

Where:

H_r = effective depth (mm) corresponding to each value of R

k = constant for a range of working temperatures and particle densities

The hydrometer analysis results for the natural and the stabilized soils at different LBWA treatment are summarized in Appendix A.

3.2.5 Atterberg limits

The Atterberg limit tests are also known as consistency tests (Braja, 1998). They include liquid limit, plastic limit, linear shrinkage and plasticity index tests.

3.2.5.1 Liquid limit

Test 1(A) B.S 1377 (1990) describes the procedure for the determination of liquid limit test of a soil which was adopted for this work. 200 g of the soil passing through the 425 μm aperture sieve size was tested. The soil was thoroughly mixed with water on a flat glass plate to form a homogenous paste.

The soil paste was then placed into the Casagrande apparatus, leveled off and a groove made by drawing the grooving tool through the centre along the diameter of the hinge. By turning the crank at the rate of two revolutions per second, the empty shell being lifted and dropped until the two parts of the soil came into contact at the bottom of the groove. The number of blows at which this occurred was recorded and some quantity of the sample was taken and its moisture content was determined. The liquid limit tests were determined at various moisture contents from drier states to the wetter states. The moisture content was plotted against the respective number of blows on the semi logarithm paper. The liquid limit was deduced as the moisture content corresponding to 25 blows.

The same procedure was repeated for the soil and the stabilizer. The soil fraction passing the BS 425µm sieve was mixed with locust bean waste ash (LBWA) prior to the test. The procedure was repeated for each soil and for various moisture contents. The test results are summarized in Appendix A.

3.2.5.2 Plastic limit

The proportion of the material passing sieve with aperture 425µm which was used for the determination of the liquid limit was also used for the determination of the plastic limit. A sample of the wet soil was taken and moulded between the palms of the two hands. The sample was rolled and sub-divided into four equal parts. Each of the portions formed were then rolled between the tips of the fingers and the surface of the glass. Sufficient pressure was then exerted to reduce the diameter of the thread to about 3mm, as specified by the BS 1377 (1990). The rolled soil which formed a thread was rolled until it shared in both ways. The plastic limit was recorded as the average of the moisture contents obtained. The procedure was repeated for every successful increment in the concentration of the locust bean waste ash.

The plasticity index (PI) was computed as the numerical difference between the liquid limit (LL) and the plastic Limit (PL) as follows:

$$PI = LL - PL \quad (3.5)$$

Result of the plastic limits as obtained from the procedures described above are summarized in Appendix A.

3.2.5.3 Linear shrinkage

150g of the soil sample passing the 425μm BS test sieve was mixed thoroughly on a glass plate with the aid of palette knives until the soil mass became a smooth homogenous paste. The soil mass was subsequently placed in a greased mould with slight clearance at the edge. The mould was the then slightly world to remove air pockets in the mixture.

The mould was then placed so that the soil water mixture could air dry slowly and subsequent drying was done at 60^{o}C to 65^{o}C until shrinkage ceased and the further dying was done 105^{o}C to 110^{o}C to complete the drying. The mean length of the dried soil was measured from the length of the top and bottom of the dried soil samples after cooling. The linear shrinkage of the soil was calculated. The procedure was repeated for every successive increment of the stabilizer (locust bean waste ash). The results are as summarized in Appendix A.

3.2.6 Determination of pH of natural and stabilized soil

The standard method used for the test covered the electrometric determination of the pH value for the natural and stabilized soils suspension. 30 g of the natural soil passing the 425 μm BS test sieve was obtained and weighed into a beaker and later 60 ml of distilled water was added to it to have a ratio of soil to water of 1:2 as specified in BS 1377(1990). The soil suspension was then stirred in the covered beaker for a few minutes and allowed to stand for 24 hours. The electrode fitted on a pH meter was then immersed in the natural soil suspension and the pH readings taken. The same process was used for the stabilized soil at different percentages of LBWA contents.

The test results for the determination of pH values for the natural and treated soils are shown in Appendix A.

3.2.7 Potential volume change

The potential volume change test was carried in accordance with the procedure outlined in Plait (1953) as well as Nelson and Miller (1992). The potential volume change test apparatus consists of a device by which the remoulded soil sample in a mould is confined between two porous stones covered with water. The water bath containing the mould is placed on the base of the framework. A plunger piece is placed on the top porous stones and then attached to the proving ring which is adjusted so that it comes in contact with the plunger piece. Pressure exerted by the soil sample is transmitted to the proving ring, the deflection of which is recorded in the dial gauge. The relationship between load and the deflection of the proving ring is determined by calibration and therefore, the applied pressure due to swelling is determined.

3.2.7.1 Preparation of test specimens

Remoulded sample

The soil type was first dried and then pulverized and passed through the sieve No. 4 in order to remove the clogs in the soil as specified by Head (1980). The exact quantity of dry soil required to make a sample of definite height in the mould at its required density was calculated and the corresponding weight of the soil is taken in a basin. The soil was mixed thoroughly at stepped percentage of the stabilizer and then compacted in the mould with the aid of compaction rammer of 2.5 kg, falling through 300 mm

providing the compaction for the British Standard Light energy. The base plate and plunger are then separated from the mould and porous stones are fitted on the top and bottom of the sample. The sample was then ready for the test. The results are presented in Appendix A.

3.2.8 Compaction

The essence of conducting compaction test was to determine the relationship between dry unit weight and moulding water content. Factors that influence the degree of compaction are the moisture content, soil type and compactive effort/energy per unit volume. Field compaction tests often vary from laboratory tests and in a bid to reduce these differences, several compactive efforts are selected in the laboratory that span the range of compactive efforts anticipated in the field, consequently the water content/dry unit weight criteria applies to any reasonable compactive effort.

Three compactive efforts were utilized throughout this work. They are British Standard light (BSL), West African standard (WAS) and the British Standard heavy (BSH).

3.2.8.1 British Standard light

In the British Standard light (BSL) compaction test, the soil was compacted in a mould that has a volume of 1000 cm^3. The diameter of the mould is 101.6 mm. During the laboratory test, the mould was attached to a base plate at the bottom of and to an extension at the top. The soil was mixed with varying amount of water and then

compacted in three equal layers by a hammer that delivers 27 blows to each layer. The hammer weighs 2.5 kg and has a drop of 304.8 mm.

3.2.8.2 West African Standard

For the West African Standard (WAS) or 'Intermediate' compaction the same size of mould used for the BSL compaction was employed with a hammer weighing 4.5 kg falling through 45 cm compacted in 5 layers, each receiving 10-blows. From each of the compacted samples, protruding soils are leveled off with a straight edge carefully. The soil samples were then removed from the mould and a little portion taken for moisture content determination.

Various percentages by weight of the locust bean waste ash (LBWA) were added to the black cotton soil again. For each of the compactive effort considered, the procedure was repeated with increment in LBWA added. The bulk density, ρ_1 in Mg/m^3 was calculated for each compacted sample as:

$$\rho_1 = \frac{M_2 - M_1}{1000} \qquad (3.6)$$

Where

M_1 = Mass of mould and base (g)

M_2 = Mass of mould, base and soil (g)

and the dry density, ρ_d in Mg/m^3 was calculated as :

$$\rho_d = \frac{100}{100+W}\rho_1 \quad \text{.....(3.7)}$$

W = Moisture content (%)

The procedure was repeated for the stabilization material by adding requisite proportions by weight of locust bean waste ash to the natural soil sample.

3.2.7.3 British Standard Heavy

With the development of heavy rollers and their use in the field of compaction, the British Standard light (BSL) compaction was modified to better represent field conditions. The revised version is referred to as the British Standard heavy (BSH) compaction.

In order to carry out test at this level of compaction, the same size of mould as used for the BSL compaction test with a volume of 1000 cm^3 was employed. However, the soil was compacted in five layers by a hammer that weighed 4.5 kg through a drop of 457.2 mm. The number of hammer blows for each layer was kept at 27 as in the case of the BSL compaction test.

The effect of locust bean waste ash (LBWA) on the maximum dry density (MDD) and the optimum moisture content (OMC) are shown in Appendix A while the curves of dry density versus moisture content for the (BSL, WAS and BSH) compaction tests at various stabilizer contents are shown in Appendix B (for each compaction test).

3.2.8 Unconfined compression

This unconfined compressive strength(UCS) was determined in accordance with BS 1377(1990). Air dried soil-locust bean waste ash mixtures were compacted at their optimum moisture content using the three energy levels stated before in 1000 cm^3 mould. After compaction, the treated soil was extruded from the mould and sealed by double wrapping in polythene bags and kept in the humidity room for a period of 48 hours to allow for uniform moisture distribution and curing, at a constant temperature of 24 ± 2^oc. After curing, the samples were trimmed into cylindrical undisturbed specimens, which were placed in a load frame machine driven strain controlled at 0.10 % / min until failure occurred. Three specimens were used for each test and the average results taken. The cylindrical samples were cast at different optimum moisture contents and different percentages of the stabilizers by using predetermined weight of soil obtained from the density – volume relationship. The pulverized soil (unstabilized) or soil plus the stabilizer were thoroughly mixed with water at the optimum moisture content and compacted into the mould at the BSL, WAS and BSH energy levels. The compacted samples were removed carefully from the mould and then placed in sealed transparent plastic bags and cured for 7, 14 and 28 days. Another set of samples were cured for 7 days under similar conditions and thereafter were removed carefully, de-waxed top and bottom and immersed completely in water for another 7 days. The strength of the cured samples were determined by placing them in platens of a universal testing machine and crushed to failure. The compressive strength for each sample was deduced from the equation:

$$Compressive\ Strength(kN/m^2) = \frac{Failure\ load}{Cross\text{-}sectional\ area\ of\ sample} \ldots\ldots (3.8)$$

The results obtained for the different concentrations of the stabilizer as well as durations of curing are shown in Appendix A.

3.2.9 Durability (durability test)

The durability assessment of the soil – locust bean waste ash mixture was done by immersing specimens in water for measurement of resistance to loss in strength rather than the wet-dry and freeze-thaw tests as highlighted in ASTM (1992) that are not effective under tropical conditions. The resistance to loss in strength was determined as ratio of the UCS of specimens wax-cured 7 days, de-waxed top and bottom and later immersed in water for another 7 days to the UCS of specimens wax-cured for 14 days. Ola (1974) reported that resistance to loss in strength should be a maximum of 80 % for 7 days curing and 4 days soaking period. Three specimens were used for each UCS, CBR and durability experiment conducted. The specimens were waxed to prevent loss of moisture by evaporation and allowed to cure under controlled conditions. The resistance to loss in strength for each sample was deduced from the equation:

$$R(\%) = P/U \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Where P = UCS for 7 days (wax cured) +7 days(soaked)

U = UCS for 14 days (wax cured)

R = Resistance to loss in strength

The durability test results obtained for the different concentrations of the stabilizer at the three compactive efforts (BSL, WAS and BSH) are shown in Appendix A.

3.2.11 California bearing ratio

The California bearing ratio (CBR) test was carried out as a measure of strength of the natural and the stabilized soil. The CBR is expressed by the force exerted by the plunger by the depth of its penetration into specimen. The tests were carried out in conformity with the prescriptions of BS 1377 (1990), BS 1924 (1990) and the Nigerian General Specification (1997).

Predetermined weights of the soil sample with or without the stabilizer were placed into the 2360 cm^3 mould and compacted at the optimum moisture content and at the three compactive efforts. For the BSL compactive effort, the soil samples were compacted in three (3) layers each receiving 62 blows from the 2.5 kg rammer. For the WAS, the soil sample was compacted in five (5) layers each receiving 25 blows from the 4.5 kg rammer while for British Standard heavy (BSH), the soil sample was compacted in five (5) layers each receiving 62 blows from the 4.5 kg rammer.

Since the weights of the soil samples were predetermined using the density – volume relationship, the soils were completely compacted into the CBR moulds. After the compaction, the base plates were removed and then the compacted specimens were placed into sealed plastic bags for curing. Plastic bags were used to avoid loss of moisture due to evaporation. The specimens were cured for six (6) days and then later fully immersed in water for 24 hours before testing in accordance with the specification by the Nigerian General Specification (1997). The specimens were removed from the

plastic bags and the base plates replaced, they were then transferred to the CBR testing machine. The plunger was then made to penetrate the specimen at a uniform rate. The dial reading indicating force was taken each at 0.25mm interval of penetration until the maximum of 7.50 mm was attained or alternatively until failure was reached. The bottom of the specimens was also tested in like manner. The CBR curves were plotted (i.e. force versus penetration of plunger) using the values obtained from the tests. The CBR was calculated at the penetrations of 2.50 mm and 5.0 mm as

$$CBR = \frac{Measured\ force}{Standard\ force} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.10)}$$

The average of the two values was recorded as the CBR where they were within 10 % of each other, otherwise the higher value was used as the CBR. The CBR values for the different concentrations of the stabilizer compacted at the three energy levels are presented in Appendix A.

CHAPTER FOUR

DISCUSSION OF RESULTS

4.1 Preliminary Tests

The results of the preliminary tests conducted for the identification and the determination of the properties of the natural soil are presented in Table 4.1 while the particle size distribution curve is shown in Fig. 4.1. The overall geotechnical index properties of the natural soil showed A-7-6 subgroup of the AASHTO Soil Classification System (AASHTO,1986) or CH in the Unified Soil Classification System (ASTM,1992). The soil is dark grey in colour and from its recorded properties, it is not suitable for road construction.

Table 4.1 Geotechnical Properties of the Natural Black Cotton Soil

Property	**Quantity**
Natural Moisture Content, %	8.9
Percent passing BS No. 200 sieve	69.1
Liquid Limit, %	50.4
Plastic Limit, %	17.1
Plasticity Index, %	33.3
Linear Shrinkage, %	15.7
AASHTO Classification, %	A-7-6
Unified Soil Classification System (USCS)	CH
pH	8.3
Specific Gravity	2.30
Swelling Pressure, kN/m^2	42.6
Maximum Dry Density, Mg/m^3	
British Standard Light (BSL)	1.59
West Africa Standard (WAS)	1.68
British Standard Heavy (BSH)	1.83
Optimum Moisture Content, %	
British Standard Light (BSL)	18.5
West African Standard (WAS)	16.8
British Standard Heavy (BSH)	14.0

Unconfined Compressive Strength, kN/m^2	
British Standard Light (BSL)	115
West African Standard (WAS)	300
British Standard Heavy (BSH)	402
California Bearing Ratio, %	
British Standard Light (BSL)	3
West African Standard (WAS)	6
British Standard Heavy (BSH)	8
Colour	Dark Grey

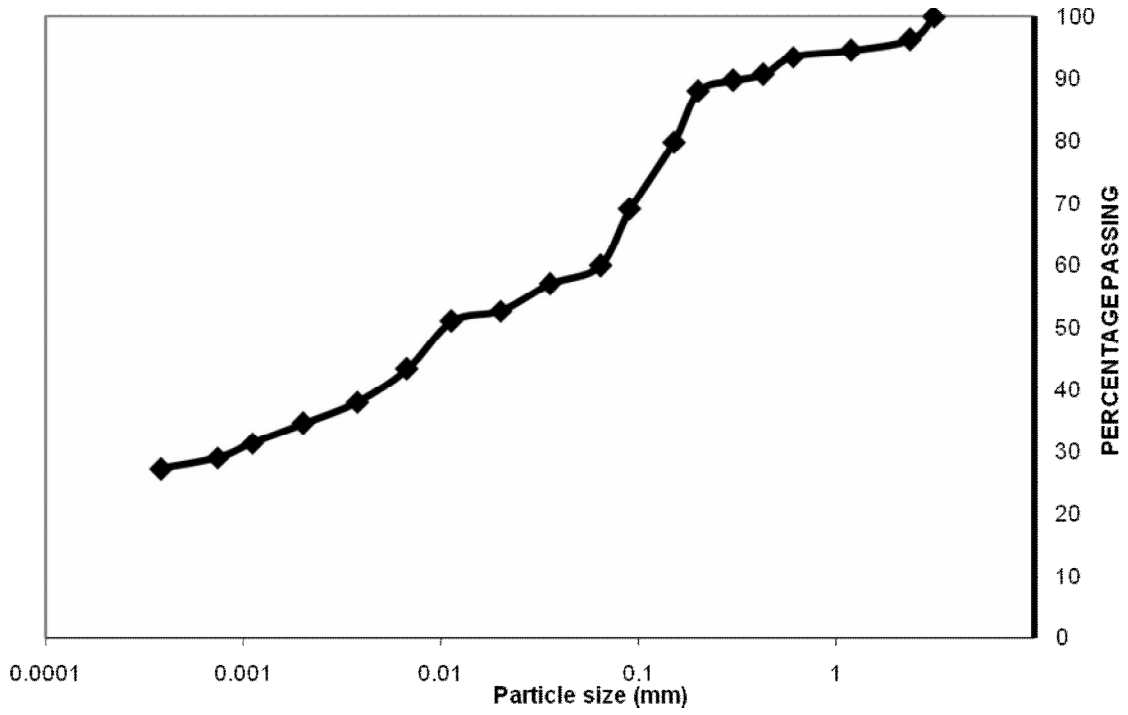


Fig. 4.1: Particle Size Distribution Curve of Natural Black Cotton Soil

4.2 Cement Rating of Locust Bean Waste Ash

Bogue's equations (see Lea, 1956) give an estimate of the potential principal compounds present in cement. These compounds are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium alumino ferrite (C_4AF). The compound compositions of locust bean waste ash were calculated using the equations

$$C_3S = 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.48(Fe_2O_3) - 2.85(SO_3) \quad \text{.....(4.1)}$$

$$C_2S = 2.87(SiO_2 - 0.754(C_3S) \quad \text{.....(4.2)}$$

$$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3) \quad \text{.....(4.3)}$$

$$C_4AF = 3.04(Fe_2O_3) \quad \text{.....(4.4)}$$

A comparison of the calculated compound composition of locust bean waste ash and a typical ordinary Portland cement is shown in Table 4.2:

Table 4.2: Calculated Compound Composition of Locust Bean Waste Ash and Typical ordinary Portland Cement

Compound	Concentration (%)	
	Locust Bean Waste ash	**Portland Cement***
C_3S	-	54.1
C_2S	-	16.6
C_3A	39.09	10.8
C_4AF	0.845	9.1

***** (Lea, 1956 using Bogue's equation)

The cementing characteristics of the locust bean waste ash are dependent on its oxide composition. It is evident that except for the calcium oxide (CaO) which is very low in the locust bean waste ash, it could be a good cementing agent.

The basic chemistry of hydrated cement paste shows that the silicates, tricalcium silicate (C_3S) and dicalcium silicate (C_2S) are the most important compounds which are responsible for the strength. However, due to the low calcium content of locust bean waste ash, these cementitious compounds are non existent. The presence of tricalcium aluminate (C_3A) in cement though undesirable is about 25% the quantity in locust bean waste ash. Osinubi (2000b) reported that the presence of tricalcium aluminate (C_3A) does not contribute to the strength gain at early ages and it reacts with sulphates to form the expansive compound, calcium sulpho-aluminate (ettringite), responsible for the so-called "sulphate attack" or ''sulphate-induced heaving". The tetracalcium alumino ferrate (C_3AF) does not contribute to strength gain.

4.3 Effect of Locust Bean Waste Ash on Particle Size Distribution

The untreated black cotton soil was pulverized and passed through BS. Sieve No. 4 as specified by Head (1980) for the purpose of removing excess clods from clayey soil. The soil was then mixed with water equivalent to its optimum moisture content. This resulted in the formation of aggregates, clods and lumps or otherwise called crumbs, in agreement with Rene (1971) who reported that the soil was being glued together by substances such as humus or cemented by calcium carbonate.

When various concentrations of locust bean ash were mixed with black cotton soil thoroughly and water corresponding to the OMC at the BSL compaction energy added, not much glaring changes were observed. The gradation of the particle sizes improved slightly with reduction in the clods as locust bean waste ash content increased. The particle size distribution curves for the stabilized soil are shown in Fig. 4.2. It is observed that there was a slight reduction in the percentage of fines from 69.1 % for the natural soil to 67.2 % at 10 % locust bean waste ash content. Not much change was noticed in the coarser sizes. This implies that the modification reaction did not as much take place between the locust bean waste ash and the coarse fraction.

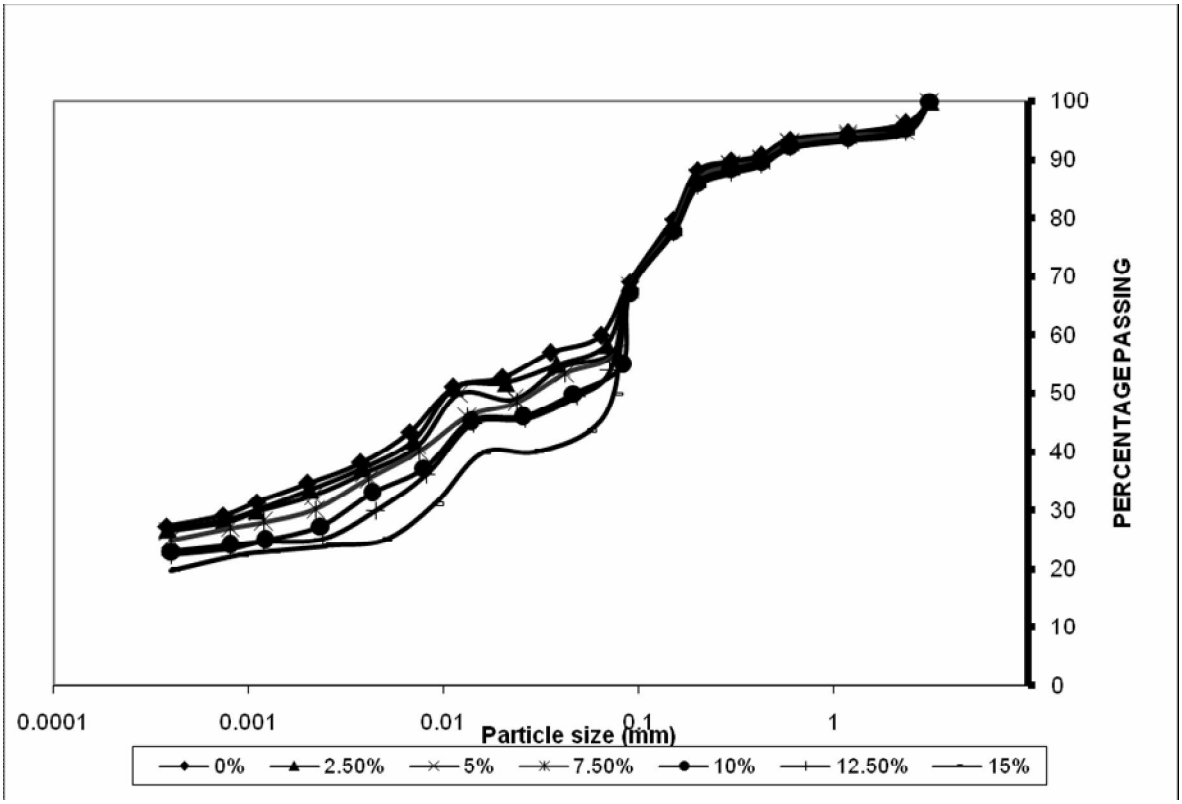


Fig. 4.2: Particle Size Distribution Curves of Locust Bean Waste Ash Treated Black Cotton Soil

4.4 Evaluation of the Effect of Locust Bean Waste Ash on the Properties of Black Cotton Soil

4.4.1 Atterberg limits

The effect of locust bean waste ash on the Atterberg limits (i.e., liquid limit, plastic limit, plasticity index and linear shrinkage) of black cotton soil is considered in this section. The variation of Atterberg limits with locust bean waste ash (LBWA) is shown in Fig. 4.3

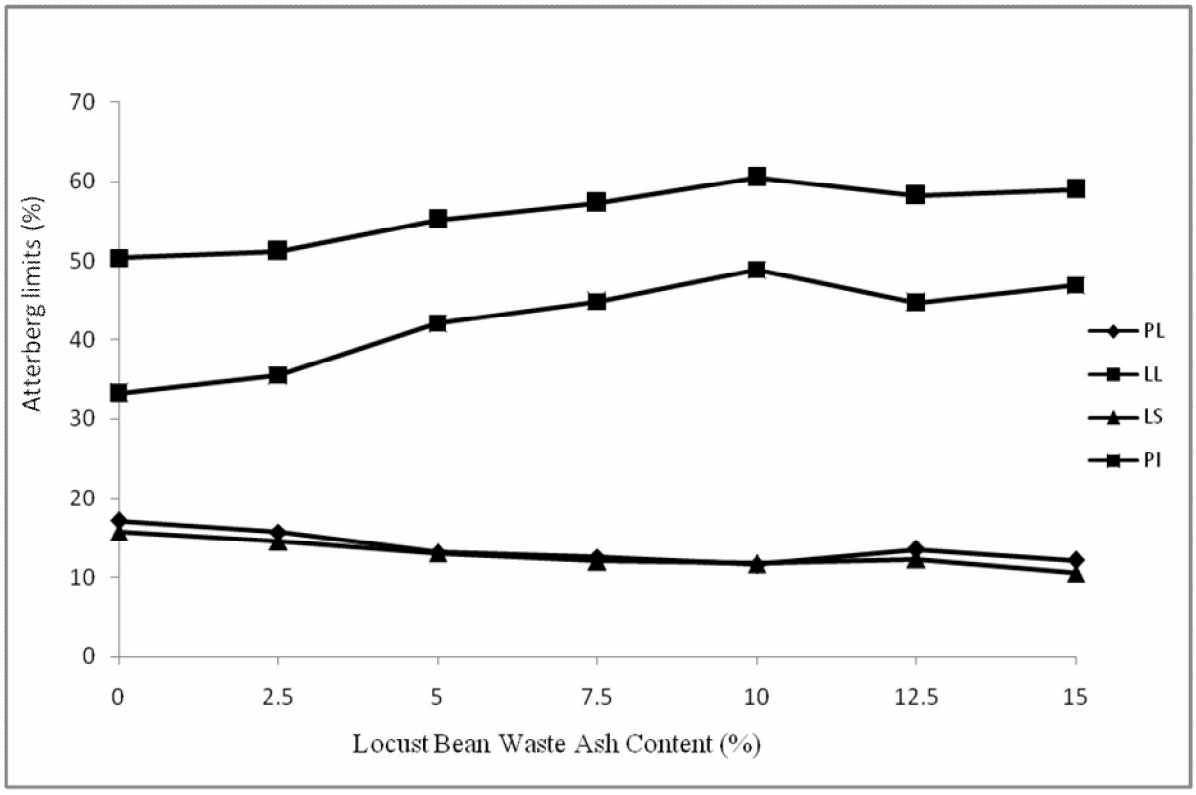


Fig. 4.3: Variation of Atterberg Limits with Locust Bean Waste Ash Content

Liquid Limit: The variation of liquid limit with locust bean waste ash (LBWA) content for treated black cotton soil is shown in Fig. 4.3. Liquid limit increased with higher LBWA content. The reaction is in agreement with the definition of liquid limit. The liquid limit of a soil is defined as the water content at which the soil exhibits dynamic shear strength. If a soil exists at its liquid limit and an alteration occurs in the system such that repulsive forces are decreased (i.e., by increasing calcium for strength) its strength increases to specific values that more water will be required to bring the soil to its dynamic shear strength (Osinubi, 1995). The liquid limit of the soil-locust bean waste ash mixture increased from the minimum value of 50.4 % at no locust bean waste ash

content to a maximum value of 60.5% at 10 % locust bean waste ash content. It can be observed from Fig. 4.3 that there was a steady increase in the liquid limit between 2.5 % to 10 % locust bean ash content. However, at 10 % locust bean ash, there was a slight reduction in liquid limit to a value of 58.2 % at locust bean ash content of 12.5 %. The increase in the liquid limit between 2.5 % and 10 % locust bean waste ash is attributable to the fact that each increase in locust bean ash introduced more pozzolanic substances from the ash (Ca^{2+}, Al^{2+}, Fe^{2+}, Si^{2+}) that required more amount of water for hydration to go to completion. The reduction in the liquid limit at 12.5 % was due to agglomeration and flocculation of the clay particles, which was a result of ion exchange at the surface of the clay particles as the Ca^{2+} in the locust bean waste ash reacted with the lower valence metallic ions in the clay structure.

Plastic limit: The variation of plastic limit with locust bean waste ash content is depicted in Fig. 4.3. Plastic limit generally decreased with higher locust bean waste content from 17.1 % for the natural soil to a minimum value of 11.6 % at 10 % LBWA treatment. The reduction in plastic limit with increase in locust bean ash content is in agreement with the findings reported by researchers (Peter, 1993; Saleh and Utpal, 1993; Osinubi, 1995, 1999) and was due to cationic exchange reaction. The more active and higher valence cations in the locust bean waste ash (i.e., Ca^{2+}) replaced the weakly bonded ions in the clay structure and this led to flocculation and liberation of water bonded at the outer layers. The increase in plastic limit at 15 % could be due to the increase in silicate and aluminum ions, which according to Gilliott (1987) and Sherwood (1957) in the presence of moisture reacted with available sulphate (1 % or less) attack

phenomenon otherwise called “sulphate induced–heaving.” The phenomenon probably led to increase in plasticity of the soil as it was exhibited at the 15 % locust bean waste ash content.

Plasticity index: The variation of plasticity index with locust bean waste ash content is also shown in Fig. 4.3. The plasticity index generally increased with LBWA content from 33.3 % for the untreated soil to a peak value of 48.9 % at 10 % LBWA content.

Linear shrinkage: Linear shrinkage generally decreased with higher LBWA content from a value 15.7 % for the natural soil to a minimum value of 11.7 % at 10 % LBWA treatment. The reasons for the reduction of the plastic limit with increase in the stabilizer content are also applicable for the reduction in linear shrinkage with higher values of locust bean waste ash content.

4.5 Compaction Characteristics.

4.5.1 Maximum dry density

The variation of maximum dry density (MDD) with locust bean ash content for the treated black cotton soil prepared at the three compactive efforts used in this study are as shown in Fig. 4.4. Generally, MDD initially increased with peak values recorded between 2.5 and 5 % LBWA content.

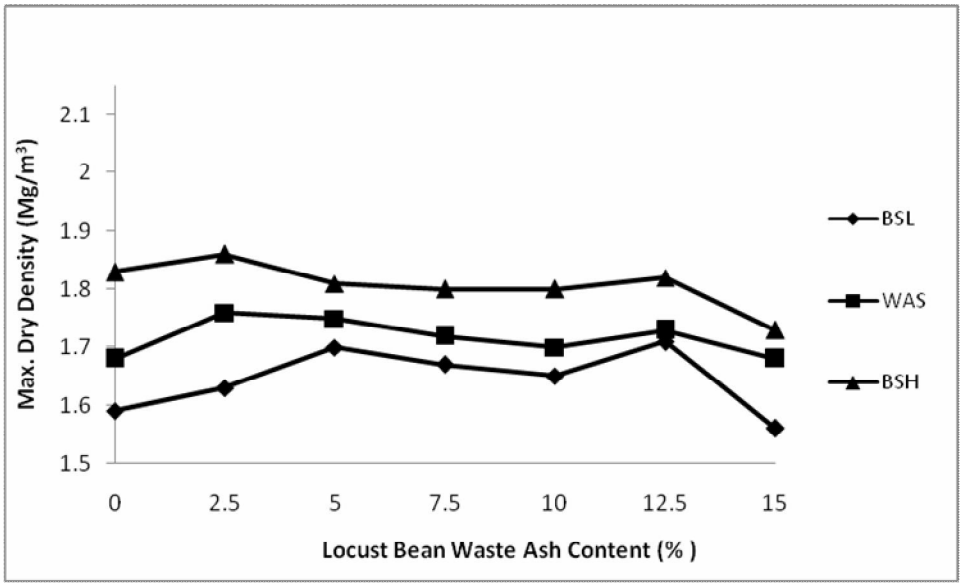


Fig. 4.4: Variation of Maximum Dry Density with Locust Bean Waste Ash content

For the British Standard light (BSL) compactive effort, the MDD of the natural soil increased from 1.59 to 1.63 Mg/m^3 at 2.5% locust bean waste ash content, 1.70 Mg/m^3 at 5 % and 7.5 % locust bean waste ash contents. However, another peak in MDD value of 1.70 Mg/m^3 was again recorded at 12.5 % locust bean waste ash content.. (see Fig. 4.4)

For the West African Standard (WAS) compactive effort, the MDD initially increased from a value of 1.68 Mg/m^3 for the natural soil to a peak value of 1.76 Mg/m^3 at 2.5 % locust bean waste ash and thereafter decreased with higher LBWA content.

The variation of the MDD with locust bean waste ash content at the British Standard heavy compactive effort is shown in Fig. 4.4. MDD increased from a value of 1.83 Mg/m^3 for the natural soil to a peak value of 1.86 Mg/m^3 at 2.5 % locust bean waste ash content and thereafter decreased.

The initial increases in MDD recorded for all the three compactive efforts are attributable to flocculation and agglomeration of the clay particles, primarily due to cation exchange. The subsequent reduction in MDD could be partly due to the flocculated and agglomerated clay particles occupying larger spaces leading to corresponding decreases in the MDD (O' Flaherty, 1988). Furthermore, the reduction in MDD with increase in locust bean waste ash could be due to the replacement of soil particles that were of higher specific gravity of 2.3 in a given volume by particles of locust bean ash of comparatively lower specific gravity of 2.0.

4.5.2 Optimum moisture content

The variation of optimum moisture content (OMC) with locust bean waste ash content for BSL WAS and BSH compactive efforts are shown in Fig. 4.5. Generally, OMC initially decreased to minimum values and later increased.

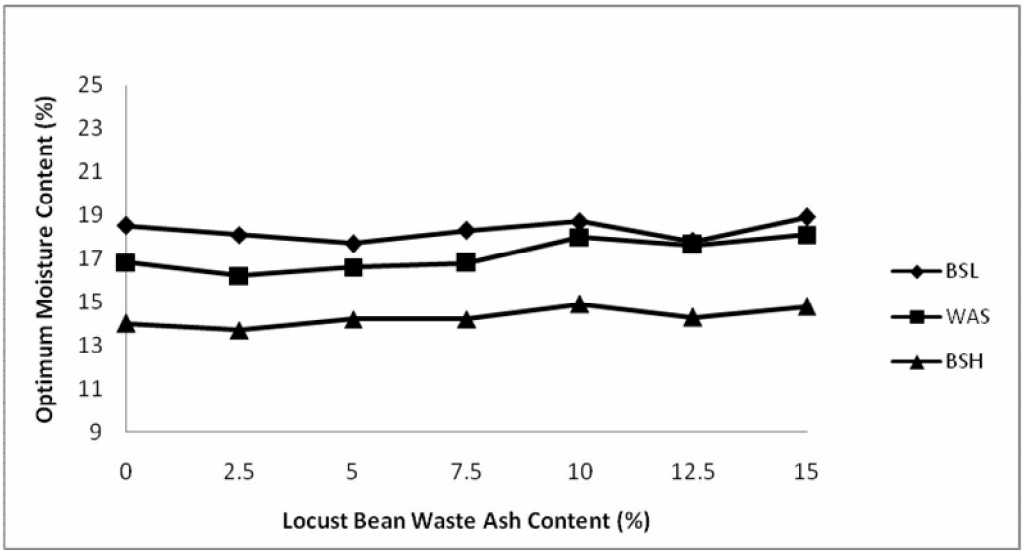


Fig. 4.5: Variation of Optimum Moisture Content with Locust Bean Waste Ash Content

For the BSL compactive effort, the OMC decreased from 18.53 % for the natural soil to a minimum value of 17.7 % at 5 % locust bean waste ash content. Further additions of locust bean waste ash led to an increase in the OMC to a maximum value of 18.7 % at 10 % and 15 % LBWA contents.

In the case of the WAS energy level, the OMC reduced from a value of 16.83 % to a minimum value of 16.2 % at the 2.5 % LBWA content. Thereafter, OMC gradually increased to a peak value of 18 % at 10 % LBWA content.

The same trend was observed for the samples compacted with the energy of the BSH. There was an initial marginal decrease from a value of 14 % for the natural soil to a minimum at 2.5 % LBWA content. Thereafter, OMC gradually increased to a peak value of 14.9 % at 10 % LBWA content.

The initial decrease in OMC was solely due to the desiccation induced by the introduction of LBWA into the soil voids that were originally occupied by both moisture and air within the natural soil. With the introduction of LBWA into the soil matrix all the available water molecules were used up in the hydration reaction with consequent lower hydration and incomplete hydration that decreased the OMCs. The increases noticed later were as a result of demand for water by various cations and the clay minerals particles to undergo hydration reaction hence the need for more moisture for reaction.

4.6 Effect of Locust Bean Waste Ash on pH of Black Cotton Soil

The pH of the medium of occurrence plays a very important role in the behavior of clay suspensions. A low pH promotes a positive edge to a negative surface interaction often leading to flocculation from suspension. Stable suspension or dispersion of clay particles often requires high pH condition i.e., an alkaline medium). The type of adsorbed cation is of great importance in influencing the behavior of the material in suspension and the nature of the fabric in sediments. Monovalent cations promote deflocculation whereas clay suspensions ordinarily flocculate in the presence of divalent and trivalent cations.

The role of pH in influencing inter-particle repulsion and the existence of positive edges charges in low pH environs is the single most important factor controlling the absorption and de-sorption of cation in a soil suspension (Mitchell, 1976).

The variation of pH with increase in locust bean waste ash stabilized soil content is shown in Fig. 4.6. The results obtained showed that pH value increased with higher locust bean waste ash treatment. This was so because of the dissociation of ions from the locust bean waste ash into the soil mass making the solution more alkaline.

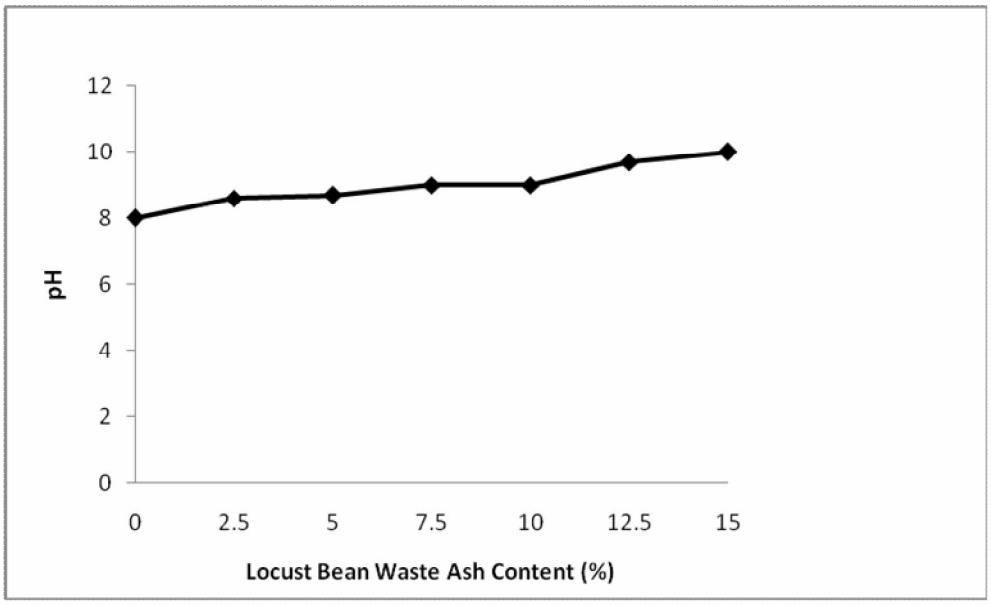


Fig. 4.6: Variation of pH with Locust Bean Waste Ash Content

4.7 Potential Volume Change

The potential volume change device was used to measure the swelling pressures of both the natural soil and the soil - locust bean waste ash mixture. The variations in swelling pressures with locust bean waste ash is shown in Fig. 4.7. Generally, swelling pressure of soil decreased with higher LBWA content. The swelling pressure reduced from a value of 42.6 kN/m^2 for the natural soil to a minimum value of 20.9 kN/m^2 at 15% LBWA treatment

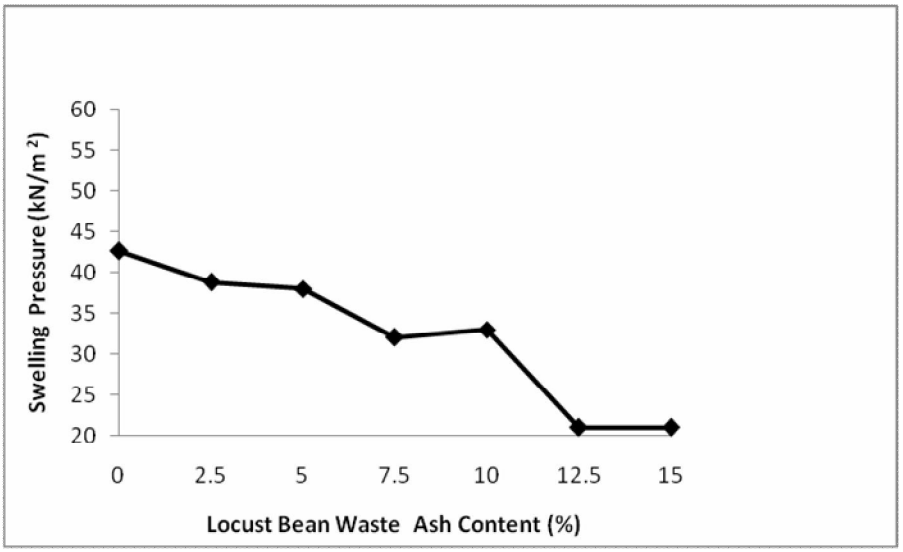


Fig. 4.7: Variation of Swelling Pressure with Locust Bean Waste Ash Content

The reduction in swelling pressure could be due to the increase in pH (i.e., alkalinity) of the soil – LBWA mixtures from 8.3 for the natural soil to 10 for soil treated with 15 % LBWA . According to Anand et al. (2005), the silicate and aluminate compounds dissolve in an environment of pH above 10 and react with Ca^{2+} to produce

cementitious compounds as it is expected. This causes a decrease in the negative charges or the lowering of the zeta potential leading to flocculation and consequent decrease in the swelling pressures.

4.8 Unconfined Compressive Strength

The relationship between unconfined compressive strength (UCS) of specimens compacted at the BSL, WAS and BSH energy levels and locust bean waste ash content are shown in Figs. 4.8 – 4.11. The variations of UCS with locust bean waste ash contents are considered separately for the different curing periods.

4.8.1 Unconfined compressive strength for 7 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 7 days are shown in Fig. 4.8. Generally, UCS values increased with higher compactive effort and LBWA content. However, it should be noted that the increase in UCS was relatively significant for specimens compacted at energy of the BSL that recorded a sharp initial increase from 114.65 kN/m^2 for the natural to a peak value of 321 kN/m^2 at 7.5 % LBWA treatment. Subsequent treatment of black cotton soil with higher dosages of LBWA did not increase the UCS substantially. For specimens compacted at the energies of the WAS and BSH, the UCS values increased from 299.96 kN/m^2 and 401.5 kN/m^2 for the natural soil to 345.16 kN/m^2 and 438.54 kN/m^2, respectively, at 2.5 % LBWA treatment. Further treatment of soil with higher dosages of LBWA did not produce appreciable increase in UCS values.

The increases in UCS observed between 0 % and 7.5 % locust bean ash content can be attributed to ion exchange at the surface of clay particles as the Ca^{2+} in the stabilizer reacts with the lower valence metallic ions in the clay microstructure which results in agglomeration and flocculation of the clay particles. The reduction in UCS at 10 % locust bean ash content was due to excess of lower valence cations that could not be neutralized with the available higher valence cations. This reaction increased the affinity for H^+ which caused a reduction in UCS values. With further increase in locust bean waste ash content the amount of cations are increased and are able to balance the net negative disequilibrium that resulted in a reduction in the affinity for H^+. This consequently led to the increase in UCS value to 336.00 kN/m^2 at 12.50 % stabilizer content.

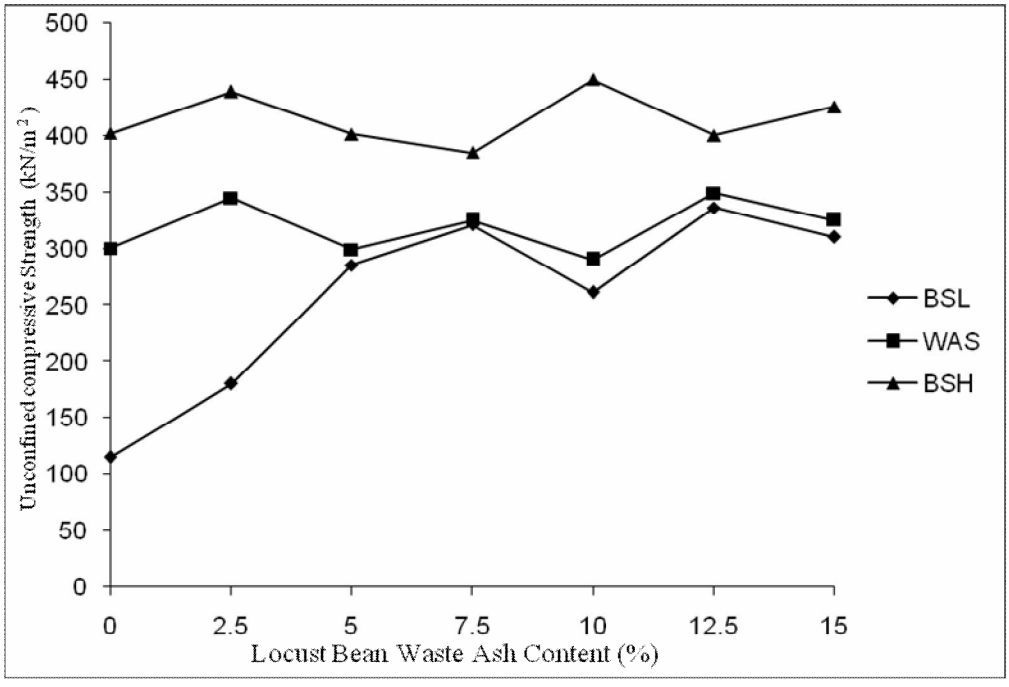


Fig. 4.8: Variation of UCS with Locust Bean Waste Ash Content (7 days curing)

4.8.2 Unconfined compressive strength for 14 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 14 days are shown in Fig 4.9. Generally, UCS values increased with higher compactive effort and LBWA content. However, it should be noted that the increase in UCS was relatively significant for specimens compacted at energy of the BSL that recorded a sharp initial increase from 141.40 kN/m^2 for the natural to a peak value of 334.96 kN/m^2 at 7.5 % LBWA treatment. Subsequent treatment of black cotton soil with higher dosages of LBWA did not increase the UCS substantially. For specimens compacted at the energies of the WAS and BSH, the UCS values increased from 310.30 and 435.58 kN/m^2 for the natural soil to 375.5 and 470.47 kN/m^2, respectively, at 2.5 % LBWA treatments. Further treatment of soil with higher dosages of LBWA did not produce appreciable increase in UCS values.

The increase in UCS at 2.5 % locust bean ash is attributable to cationic exchange reaction which led to flocculation and a consequent increase in strength while the reduction in UCS recorded at 5 % locust bean ash content was due to the deflocculation induced by the disequilibrium in the cationic exchange reaction. The same reason can be advanced for the increase observed for the UCS at 7.5 % locust bean waste ash content at the British Standard light compactive energy.

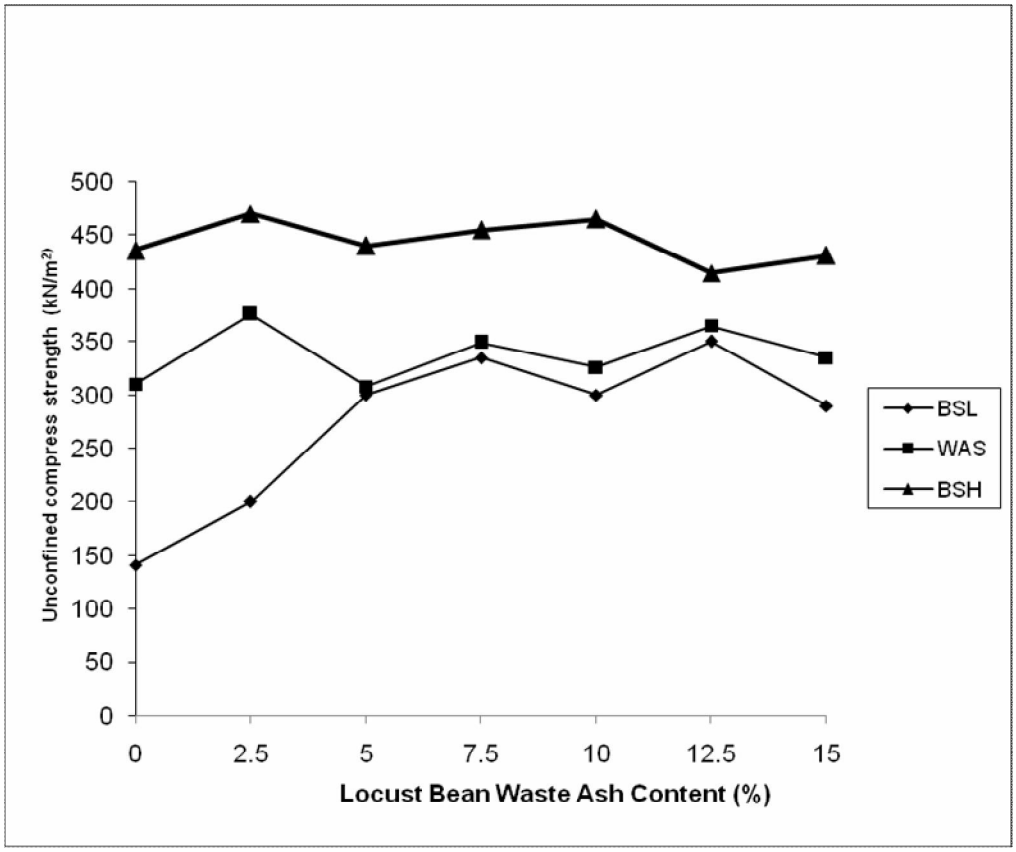


Fig. 4.9: Variation of UCS with Locust Bean Waste Ash Content (14 days curing)

4.8.3 Unconfined compressive strength for 28 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 28 days are shown in Fig. 4.10. Generally, UCS values increased with higher compactive effort and LBWA content. However, it should again be noted that the increase in UCS was relatively significant for specimens compacted at energy of the BSL that recorded a sharp initial increase from 211.70 kN/m^2 for the natural to a peak value of 424.86 kN/m^2 at 7.5 % LBWA treatment. Subsequent treatment of black cotton soil with higher dosages of LBWA decreased the UCS slightly. For specimens compacted at the energies of the WAS and BSH,the UCS values increased from 389.75

and 562.8 kN/m^2 for the natural soil to 457.44 kN/m^2 at 7.5 % LBWA and 629.60 kN/m^2 at 5% LBWA treatments. Further treatment of soil with higher dosages of LBWA did not produce appreciable increase in UCS values.

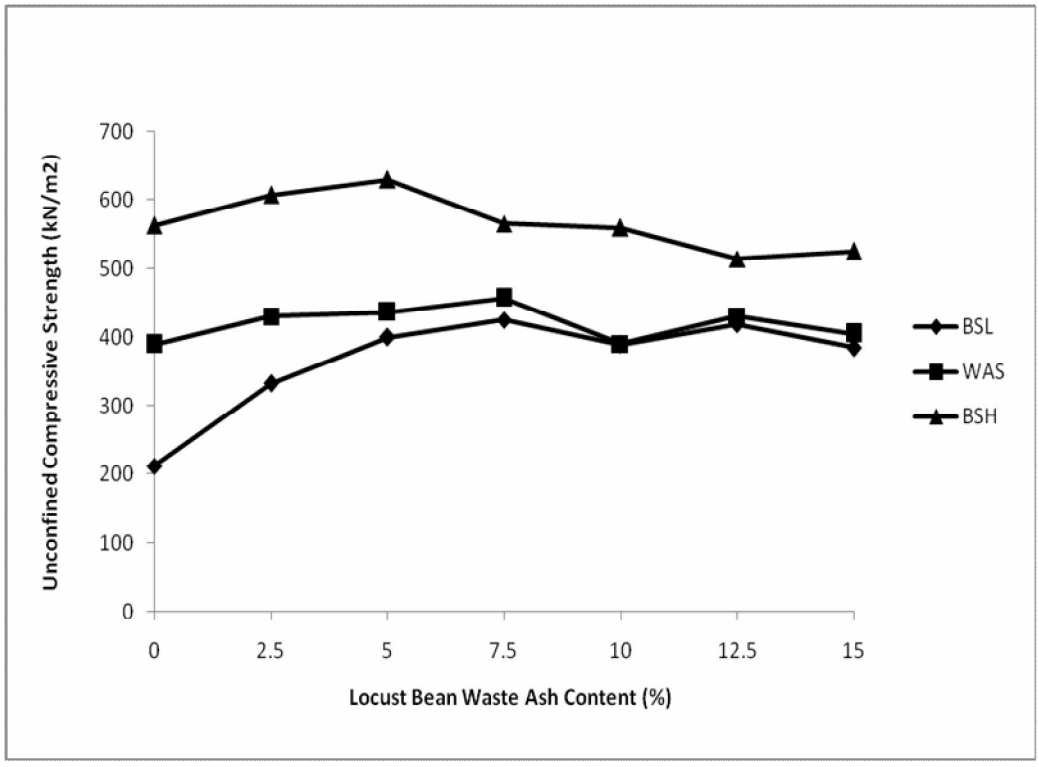


Fig. 4.10 :Variation of UCS with Locust Bean Waste Ash Content (28 days curing)

The increases are due to formation of weakly formed bonds between the clay mineral surface and the water molecules. The formation of these bonds resulted in an increase in strength with the passage of time. However, the increase in strength could also be attributed to the presence of iron oxide (goethite) which dehydrates with time to

yield higher strength in agreement with Nixon and Skipp, (1957), Little (1967) and Osinubi (2001a).

4.8.4 Unconfined compressive strength for 7 days (waxed cured) and 7 days (soaked) curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and wax cured initially for 7 days and later soaked for same duration are shown in Fig 4.11. Generally, UCS values increased with higher compactive effort and LBWA content. However, it should again be noted that the increase in UCS was relatively significant for specimens compacted at energy of the BSL that recorded a gradual initial increase from 20 kN/m^2 for the natural to a peak value of 39.87 kN/m^2 at 7.5 % LBWA treatment. Subsequent treatment of black cotton soil with higher dosages of LBWA did not increase the UCS appreciably. For specimens compacted at the energies of the WAS and BSH, the UCS values increased from 22.4 and 30 kN/m^2 for the natural soil to 45.56 and 54.45 kN/m^2 respectively at 12.5 % treatment. Further treatment of soil with higher dosages of LBWA reduced the UCS values.

It is pertinent to note here that the UCS values for the soaked soil specimens are far lower than that obtained for the 7, 14 and 28 days curing periods which is expected because of the loss in strength due to ingress of water. However, the same reasons for the initial increase and later reduction in UCS values as stated above are also applicable here.

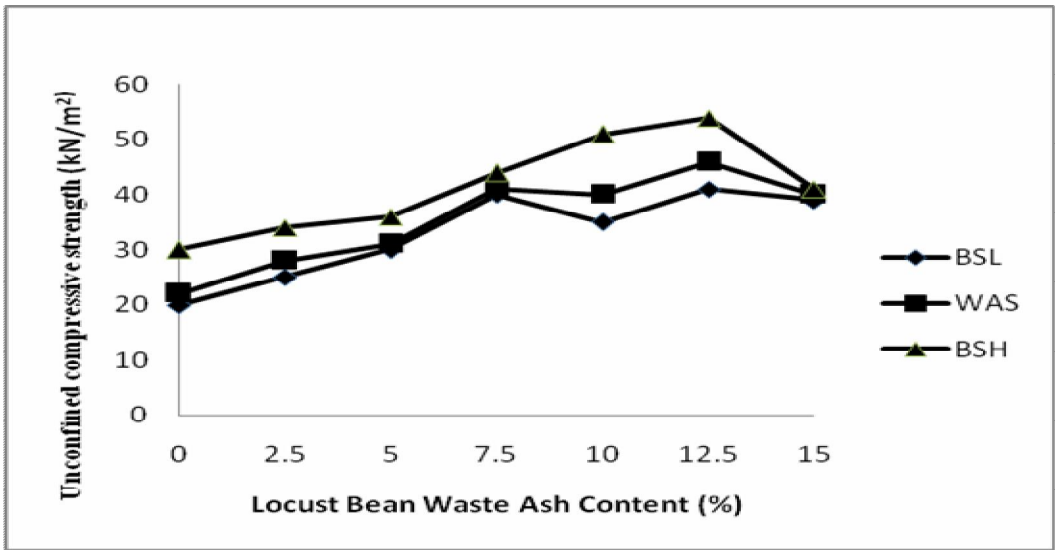


Fig. 4.11: Variation of UCS with Locust Bean Waste Ash Content (7 days wax-curing and 7 days soaking)

4.9 Durability of Locust Bean Waste Ash Stabilized Black Cotton Soil

Durability assessment of a stabilized soil is equally or even more important than the strength gained by the treated soil. Durability was evaluated by immersing specimens in water for measurement of resistance to loss in strength which is more acceptable for tropical regions like Nigeria (Ola, 1974). The resistance to loss in strength was determined as a ratio of the unconfined compressive strength (UCS) of specimens wax-cured for 7 days, de-waxed top and bottom to permit absorption of water and later immersed . Ola (1974) reported that loss in strength should be a maximum of 20 % for 7 days curing and 4 days soaking periods.

4.9.1 Effect of curing period on locust bean waste ash stabilized black cotton soil.

The mechanism of reaction between cement or pozzolanic substances and soil particles has been reported by researchers (Diamond and Kinter, 1965; Kedzi, 1979) who postulated that the modification of soil by cement or lime is due to the dissolution of the silicates and aluminates of the soil particles in a high pH environment caused by the highly reactive lime-product of hydration of cement. The reaction is reported to be in two stages:

(a) Rapid process during which the plastic properties improve, but little permanent strength developed.

(b) A latter slow process of strength development with the formation of cementitious products

The locust bean waste ash utilized in this research contains 1.08 % calcium oxide by concentration. The mixture of the black cotton soil and locust bean waste ash is alkaline with a pH of 10.0 and this provided a conducive environment for the dissolution of silicates and aluminates in the soil that reacted with calcium cations (Ca^{2+}) to form cementitious compounds through the hydration process. The hydration products formed are the tricalcium silicate, dicalcium silicates, tricalcium aluminates and tetracalcium aluminate hydrates. The tricalcium silicates were responsible for the early gain in strength while the dicalcium silicates were responsible for the later gain in strength which is a slow process otherwise called the pozzolanic reaction.

In order to study the development or decline in strength of the bonds of the treated soil, the 7-day UCS of specimens prepared at the three compaction energy levels were used as basis for comparison with strength gains at 14 and 28 days curing periods

(see Fig. 4.12). It was observed that the unconfined compressive strength for 14 days curing period increased by 1.04 times that of 7 days while the UCS value for 28 days increased by 1.3 times that of 7 days, respectively. It is also pertinent to note here that the 7 days UCS value of 336 kN/m^2 did not meet the standard value of 1720 kN/m^2 (TRL, 1993).

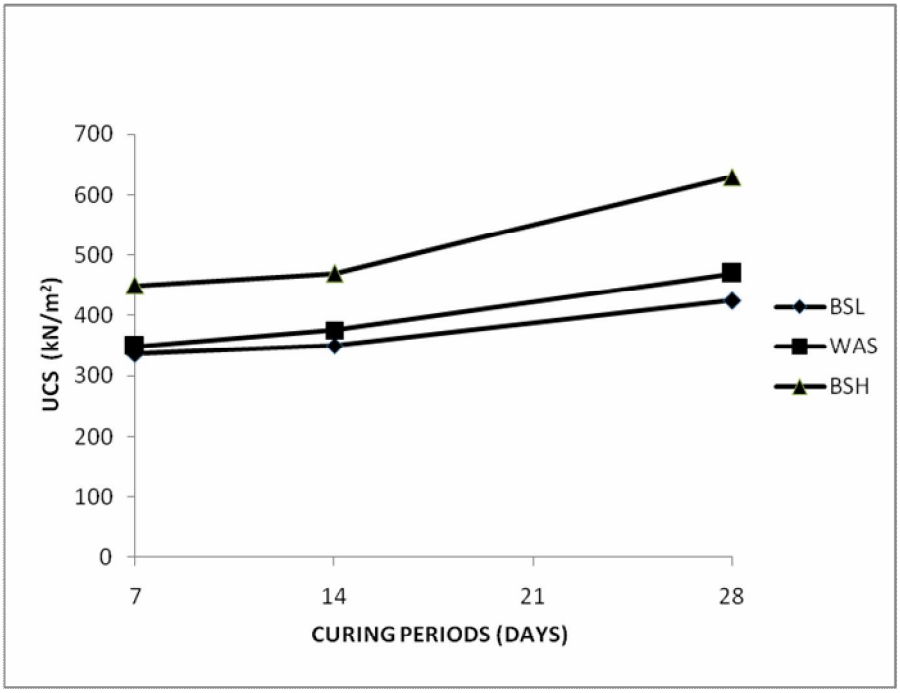


Fig. 4.12: Variation of UCS with Curing Period

4.9.2: Effect of immersion in water on the strength of locust bean waste ash stabilized black cotton soil

The variation of resistance to loss in strength with increase in locust bean waste ash stabilized soil content is shown in Fig. 4.13. The highest resistance to loss in strength is 14.2 % (i.e., 85.8 % loss in strength) at the BSL compactive efforts, 13.7 % (i.e., 86.3 % loss in strength) at the WAS energy and 13 % (i.e., 87 % loss in strength) at the BSH compactive efforts. The higher compactive efforts (WAS and BSH) recorded the least resistance to strength loss. The reason was because the UCS specimens compacted at BSL contained higher moisture and did not absorb much water contrary to the other two energy levels which at the time of compaction had lower moisture contents and therefore needed to absorb much moisture, hence their inability to resist strength loss.

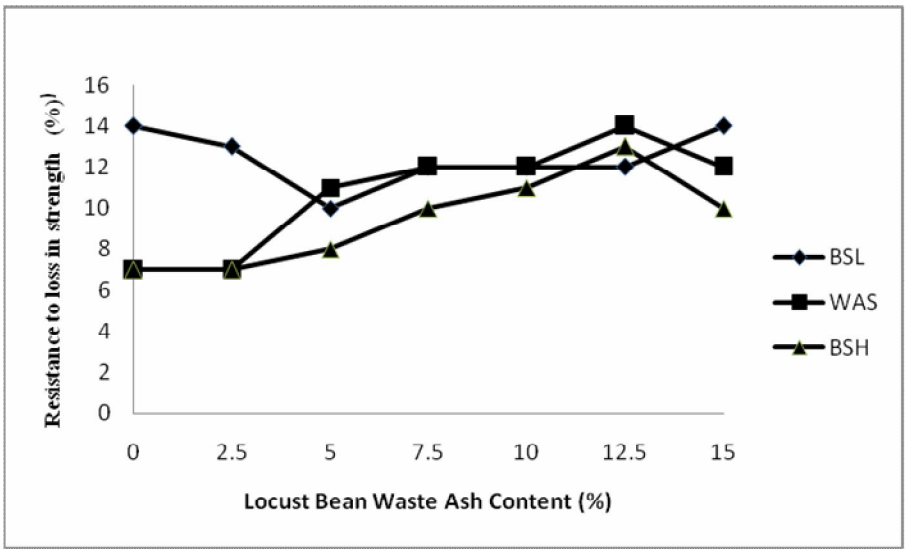


Fig. 4.13: Variation of Resistance to Loss in Strength with Locust Bean Waste Ash Content

TRL (1993) recommends the minimum requirement that must be met for a stabilized soil to be used for pavement construction in terms of its UCS and the durability requirements. The 7-day UCS value obtained for 7.5 % locust bean waste ash stabilized black cotton soil at BSL energy level was 321 kN/m^2 which did not match the conventional 1720 kN/m^2 value, while the resistance to loss in strength was about 11.9 % (i.e., 89.1 % loss in strength) was far below the minimum 80 % resistance to loss in strength (i.e., maximum 20 % allowable loss in strength) for a 7 day curing dry and 4 day immersion period reported by (Ola (1974) and Osinubi (2001a) regardless of the harsher 7 days immersion period used in this study.. Based on the above, the locust bean waste ash stabilized black cotton soil specimen did not meet the minimum durability requirement for use in pavement construction.

4.10 California Bearing Ratio

The California bearing ratio (CBR) values of the treated black cotton soil generally increased with higher locust bean waste ash contents and compactive efforts as shown in Fig. 4.14. CBR of the natural soil compacted at the energy levels of BSL, WAS and BSH are 3, 6 and 8 %, respectively. Peak CBR values of 7, 8 and 12 % were obtained at 12.5 % LBWA treatment for BSL, WAS and BSH compactive efforts, respectively. The reason for the slight increase in CBR values could be due to inadequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) which is the major compound required for development of strength.

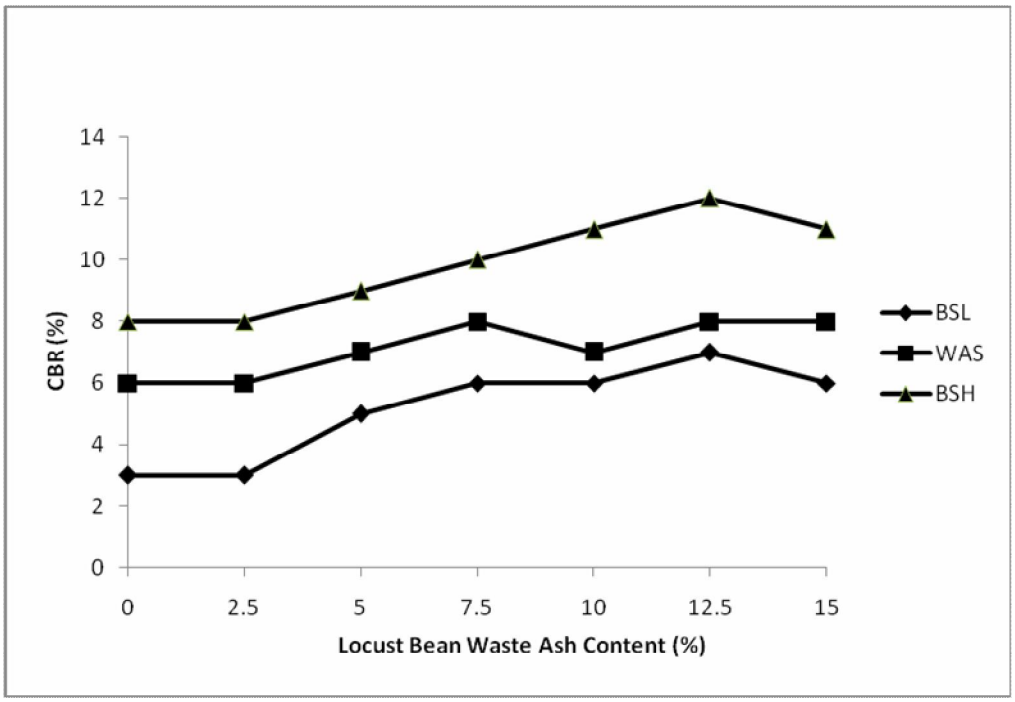


Fig. 4.14: Variation of CBR with Locust Bean Waste Ash Content

The Nigerian General Specification (1997) recommends that a CBR value of 180 % should be attained in the laboratory for cement stabilization. However, an unsoaked CBR value of 80 % is required for bases and soaked value of 30 % for sub-bases both when compacted at optimum moisture and at 100 % West African Standard compaction.(Gidigasu and Dogbey 1980; Gidigasu, 1982; Osinubi, 2001a). The CBR values recorded for the locust bean waste ash stabilized soil at the three compactive efforts are far below those prescribed in literature. It implies that locust bean waste ash cannot be used as a 'stand alone' additive.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

A research work was undertaken to investigate the effect of locust bean waste ash on the geotechnical characteristics of black cotton soil. The following conclusions can be drawn from the study:

The natural soil used in the work is an A-7-6(13) soil according to the AASHTO soil classification system or CH in the Unified Soil Classification System. It is highly clayey with 69.1 % of the natural soil passing the BS No. 200 sieve. It has high liquid limit, plastic limit, plasticity index and swelling pressures. Strength characteristics (i.e., UCS and CBR) are also very low thus making it not fit for geotechnical engineering use in its natural state.

The swelling pressure of the natural soil reduced from 42.6 to 32.2 kN/m^2 when it was treated with 7.5 % locust bean waste ash. Reduced swelling pressure indicates that the soil would not heave detrimentally under foundation loads.

The gradation of the particle sizes improved slightly with reduction in the clods as locust bean ash content increased. There was a slight reduction in the percentage of fines from 69.1 % for the natural soil to 67.2 % at 10 % locust bean waste ash content. Not much change was noticed in the coarser sizes. This implies that the modification reaction did not as much take place between the locust bean waste ash and the coarse fraction.

A maximum liquid limit value of 60.5 % and minimum plastic limit value of 11.6 % were recorded at 10 % locust bean waste treatment. The plasticity index values for all the dosages of the locust bean waste ash considered exceeded the 30 % value prescribed for subgrade by the Nigerian General Specification (1997).

The maximum dry density values of 1.59, 1.68 and 1.8 Mg/m^3 recorded for the natural soil when compacted at the three energy levels of the BSL. WAS and BSH, respectively, increased to peak values 1.7, 1.72 and 1.8 Mg/m^3, respectively, on treatment with 7.5% locust bean waste ash content.

The optimum moisture content values of 18.53, 16.83 and 14 % recorded for the natural soil when compacted at the three energy levels of the BSL. WAS and BSH, respectively, decreased to minimum values 17.7, 16.6 and 13.7 % respectively, on treatment with 5 to 7.5 % locust bean waste ash content. This trend is good in the tropics as less moisture is needed to achieve high compaction.

The unconfined compressive strength (UCS) values for BSL, WAS and BSH compactive efforts recorded for the natural soil at 7 days curing period were 114.65, 299.96 and 401.50 kN/m^2, respectively. For the same curing period the UCS values of the treated soil increased to 321, 325.15 and 384.5 kN/m^2 for the three compaction energies, respectively, at 7.5 % locust bean waste ash content. However, these UCS values are low and consequently, the treated soil cannot be used alone as pavement material.

The durability of the treated soil was determined in terms of its resistance to loss in strength by immersion in water. The resistance to loss in strength for the black cotton

soil treated with 7.5 % locust bean waste ash content was about 11.9 % (i.e., 89.1 % loss in strength) for specimen compacted at the energy level of BSL. The recorded loss in strength, regardless of the longer immersion period is more than four times the required maximum 20 % allowable loss in strength for a 7 day curing dry and 4 day immersion period(Ola,1974). It implies that locust bean waste ash cannot be used as a 'stand alone' stabilizer.

The CBR values of 3, 6 and 8 % for the natural soil compacted at the energy levels of the BSL, WAS and BSH, respectively, slightly increased to peak values of 6, 8 and 12 %, respectively, when treated with 7.5 % locust bean waste ash. The peak CBR value of 12 % recorded for the treated soil using the BSH compactive effort does not meet the minimum requirement of 15 % prescribed by the Nigerian General Specification (1997) for subgrade materials compacted at the BSL energy level.

Using the Nigerian General Specifications (1997) requirements, the strength gains recorded for black cotton soil from Numan – Ngurore borrow pit treated with an optimal 7.5 % locust bean waste ash are not adequate alone for the construction of road pavement. Although the soil properties improved comparatively at an optimal 7.5 % locust bean waste ash treatment, it is uneconomical to stabilize the material alone using locust bean waste ash.

5.2 Recommendation

Locust bean waste ash cannot be used as a stand alone or single stabilizer because it is a Class N pozzolana that contains very little calcium needed for pozzolanic reactions. However, locust bean waste ash can be used as a modifier or in admixture

stabilization of black cotton soil and hence cutting down the cost of cement or lime stabilization.

REFERENCES

AASHTO (1986). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. 14th Edition, American Association of State Highway and Transportation Officials, Washington D.C.

Agboola O. (1991).*The Effects of Stabilization on Black Cotton Soil.* M.Sc Thesis, Department of Civil Engineering Ahmadu Bello University, Zaria.

Akolo, F.P. (2000).*Rheological Properties of Makuba Stabilized Soilcrete Blocks*. Final Year project submitted to the Civil Engineering Department, Ahmadu Bello University, Zaria.

Anessi, T.H. (1968). *Strength and Consolidation Properties of Raw and Stabilized Oklahoma Shales.* Unpublished Ph.D. Dissertation, University of Oklahoma, Norman, Oklahoma..

Anand J.P, Nepat, I. and Rajan, K.V (2005). "Experimental Studies on Ettringite-induced Heaving in Soils". *Journal of Geotechnical and Geoenvironmental Engrg.* ASCE, Vol. 131 No. 3. pp325 – 335.

ASTM (1992). *Annual Book of Standards.* Vol. 04.08, American Society for Testing and Materials, Philadelphia.

ASTM C618 -78 (1978).*Specification for Fly Ash and Raw or Calcined Natural Pozzolanas for Use as a Mineral Admixture in Portland Cement Concrete*. American Society for Testing and Materials, Philadelphia.

Balogun, L.A (1990). "Foundation investigation and design techniques for residential buildings on expansive black cotton soils." *The Nigerian Engineer.* Vol. 20, No. 2, pp. 34-41.

Bowles, J. E (1979).*Physical and Geotechnical Properties of Soils.* McGrawhill International Books Company, New York.

Braja, M.D. (1998). *Principles of Geotechnical Engineering*. 4th Edition, PWS, Publishing Division of International Thomas Publishing Company, New York.

BS 1377 (1990). *Methods of Testing Soil for Civil Engineering Purposes*. British Standards Institute, London.

BS 1924, (1990). *Methods of Test for Stabilized Soils.* British Standards Institute, London.

Chen, F. H (1988). *Foundations on Expansive Soils.* Elsevier Scientific Pub. Co., Amsterdam.

Chu, Shi-Chih and Kao, Hsiang (1993). "A study of engineering properties of a clay modified by fly ash slag." In: *Fly Ash for Soil Improvement.* K D Sharp (ed), Geotechnical Engrg. Division of the ASCE, *Geotechnical Special Publications* No. 36, pp 88-99.

CokCa, E. (2001). "*Use of Class C Fly Ashes for the Stabilization of Expansive soils*". Journal of Geotechnical Engineering, Vol. 127. No7. pp. 568-573.

Czernin, W. (1962). *Cement Chemistry and Physics for Civil Engineers.* Crosby Lockwood, London.

Diamond, S., and Kinter, E.B. (1965). "Mechanism of soil-lime stabilization". Highway Research Record. 92, pp. 83-102.

Fakiyesi, F.R. and Osinubi, K. J. (1995) 'Economic utilization of a solid mineral waste resource - Phosphatic Waste.' *Abstracts Volume of 31st Annual Conference of Nigerian Mining and Geosciences Society*, 12 - 16 March, Calabar, Nigeria, pp. 37 - 38.

Fakiyesi, F. R. and Osinubi, K. J. (1996). 'Engineering use of superphosphate fertilizer processing residue.' *Abstracts Volume of 32nd Annual Conference of Nigerian Mining and Geosciences Society*, 10 -14 March, Benin, Nigeria, p. 65.

George, M.(2006).*Stabilization of Black Cotton Soil with ordinary Portland Cement using Bagasse Ash as Admixture.* M.Sc Thesis, Department of Civil Engineering Ahmadu Bello University, Zaria.

Gidigasu, M.D. and Dogbey, J.L.K. (1980). "Geotechnical characteristics of laterized decomposed rocks for pavement construction in dry sub-humid environment." *Proc. 6th Southeast Asian Conf. on Soil Engrg.* Taipei, Vol. 1. pp. 492-506.

Gidigasu, M.D (1982). "Importance of material selection,construction control and field performance studies in developing acceptance specification for laterite paving gravels."Solos and Rocha,Rio de Janeiro, Brazil,Vol.5, No. 1.

Gilliot, J. E. (1987). *Clay in Engineering Geology*. Elsevier Publishing Company, Amsterdam.

Gromko, G. J. (1974). "Review of expansive soils." *Journal of Geotechnical Engineering Div.* ASCE, Vol. 100, No. GT6, pp. 667 – 687.

Habercom, G. E. (1976). *Soil Stabilization. (A Bibliography with Abstracts).* National Technical Information Service Biblio. 221pp.

Hausman, M. R (1990). *Engineering Principles of Ground Modification.* McGraw – Hill, New York.

Head, K.H (1980**).** *Manual of Soil Laboratory Testing Vol. 1: Soil Classification and Compaction***.** Pentech Press, London, Plymouth.

Ibrahim, A (1977). "Research into the failure of soil / sand bituminous stabilized base in Maiduguri – Gamboru Road, Borno State Nigeria and it's job solution." *Conference on Material Testing, Control and Research*, Lagos, Nigeria.

Jha, J. and Sinha, S. K. (1993). *Construction and Foundation Engineering*. 5th Edition. Khana Publishers, Delhi.

Jones, D. and Holtz, J. (1973). "*Expansive soils. Hidden Disaster*" Civil Engineering, Vol. 43, pp 54.

Kedzi A. (1979)." Stabilized Earth Roads" Elsezier, Amsterdam, pp. 327.

Kawamura, M. and Diamond, S (1975). "Stabilization of fly ash soils against erosion loss." *Purdue and Indiana State Highway Commission, JHRP-75-4. Tech. Paper*, pp. 31-38.

Kumar, S. (1974). *A Study of the Effects of Simulated Weathering and Repeated Loads on Four Lime Stabilized Okhlahoma Shales*. Unpublished Ph.D dissertation, University of Oklahoma, Norman, Oklahoma.

Lagurous, J.G. and Keshawarz, M.S. (1987). *Construction and performance of the stabilized base course on U.S. 77 Ponca City Kay County.* Report No: ODOT 83-07-2 (item No. 2128); ORA 155-487, the University of Oklahoma.

Lea, F. M. (1956). *The Chemistry of Cement and Concrete*. 2nd edition. Edward Arnold (Publishers) Ltd. London.

Little A.L (1967) "The use of tropically weathered soil in the construction of earthdams." *Proc. Of 3rd Asian Reg. Conf. Soil Mech & Foundation Engrg*., Haifa, Israel, Vol.1, pp 35-41.

Markwick, A. H. D. (1944)."The basic principles of soil compaction and their application." *Institute of Civil Engineering*, London, Road Engineering Div., Road Paper No. 16.

Medjo .E. and Riskowiski, G. (2004). "A procedure for processing mixtures of soil, cement and sugar cane bagasse." *Agricultural Engineering International Journal of Scientific Research and Development* Manuscript BC 990, Vol. III, pp. 1-6.

Mitchell, J . K. (1976). *Fundamental of Soil Behaviour*. John Wiley and Sons,Incorporated, pp. 422.

Mohammed, M.S. (1997). *Improved Solid Soilcrete blocks for Low-Cost Buildings.* Final Year project submitted to the Civil Engineering Department, Ahmadu Bello University, Zaria.

Mohammedbhai, G.T.G and Baguant, B.T (1990). "Possibility of using bagasse ash and other furnace residue as partial substitute for cement in Mauritius." *Revue Agricole et Suclriere de l'lle Maurice,* Vol. 64, No. 3, pp 1-10.

Morin, W. J. (1971). "Properties of African tropical black clay soils.". *Proceedings 5th Regional Conference for Africa on Soil Mechanics and Foundation Engineering* Luanda, Vol. 1, pp. 51-59.

NBRRI (1983). "Engineering properties of black cotton soils of Nigeria and related pavement design" *NBRRI Research Paper* No. 1, p. 22.

Nelson, D. and Miller, J. (1992). *Expansive Soils Problems and Practice in Foundation and Pavement Engineering.* John Wiley and Sons, Inc., New York.

Nicholas, J. G and Lester, A. H (1999). *Traffic and Highway Engineering*. 2nd edition. Books/Cole Publishing Company, New York, U.S.A.

Nigerian General Specifications (1997). *Roads and Bridgeworks*. Federal Ministry of Works, Lagos, Nigeria.

Nixon.I.K and Skipp.H.O.(1957)."Airfield construction on overseas soils and laterite."*Proc. of British Inst. Civil Engrg.*,London,United Kingdom.Vol.8,pp.253-292.

O'Flaherty. C.A (1988). *Highway Engineering.* Vol. 2, Edward Arnold, London.

Ola, S.A. (1974). "Need for estimated cement requirements for stabilizing lateritic soil." *J. Transp. Div., ASCE,* Vol. 17, No. 8. pp 379-388.

Ola, S.A (1978) "The geology and geotechnical properties of the black cotton soils of North Eastern Nigeria." *Engineering Geology*, Vol. 12, pp. 375-391.

Ola S.A. (1983)."The geotechnical properties of black cotton soils of North Eastern Nigeria." In: S.A Ola(ed). *Tropical Soils of Nigeria in Engineering Practice.* Balkema, Rotterdam, pp. 260-178.

Osinubi K.J. (1995). "Lime modification of black cotton soils." *Spectrum Journal,* Vol. 2, Nos. 1 and 2, pp. 112-122.

Osinubi, K. J. (1997). 'Soil stabilization using phosphatic waste.' *Proceedings 4th Regional Conference on Geotechnical Engineering, GEOTROPIKA '97*, Johor Bahru, Malaysia, 11 - 12 November, pp. 225 – 244.

Osinubi, K. J. (1998a). 'Laboratory investigation of engineering use of phosphatic waste.' *Journal of Engineering Research*, University of Lagos, Vol. JER-6, No. 2, pp. 47 – 60

Osinubi K.J (1998b). "Stabilization of tropical black clay with cement and pulverized coal bottom ash admixture." In: *Advances in Unsaturated Geotechnics*. Edited by Charles D., Shackelford,Sandra L.Houston and Nien – Yin Chang. ASCE *Geotechnical Special Publication*, No. 99, pp. 289 – 302.

Osinubi, K.J (1999). "Evaluation of admixture stabilization of Nigerian black cotton soils." *NSE Technical Transaction*, Vol. 34, No. 3, pp 88-96.

Osinubi K.J (2000a). "Laboratory trial of soil stabilization using pulverized coal bottom ash." *Nigerian Society of Engineers Technical Transaction,* Vol. 35, No. 4, pp. 13-21.

Osinubi K.J (2000b), "Treatment of laterite with anionic bitumen emulsion and cement. A comparative study" *Ife Journal of Technology*, Obafemi Awolowo University; Ile – Ife, Vol. 9 No. 1 pp. 139-145.

Osinubi K.J (2001a) "Influence of compaction energy levels and delays on cement – treated soil." *NSE Technical Transaction Vol. 36, No. 4.*

Osinubi K.J (2001b) "Stabiization of lateritic soil with cationic bitumen emulsion" *Journal of Engineering Research*, Vol. JER-9, No 384, pp. 137-150.

Osinubi, K. J and Bajeh, I. (1994)."Bituminous stabilization of laterite." *Spectrum Journal* , Vol. 1, No. 2, pp. 104-112.

Osinubi, K. J. and Toro, A. (1996). 'Evaluation of superphosphate fertilizer processing residue (SFPR) and Portland cement admixture on black cotton soil.' *Programme and Abstracts Volume of Kaduna Polytechnic Annual National Conference - Recent Findings In Engineering Practice*, 11 - 12 December, p. 12.

Osinubi, K. J. and Toro, A. (1997). 'Evaluation of admixture stabilization of Black Cotton soil.' *Proceedings 4th Regional Conference on Geotechnical Engineering, GEOTROPIKA '97*, Johor Bahru, 11 - 12 November, Malaysia, pp. 273 – 289.

Osinubi, K.J. and Medubi, A. B. (1997a). "Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation." *Proceedings of 4th International Conference on Structural Engineering Analysis and Modeling (SEAM 4),* Kumasi, Ghana, 9-11 July, Vol. 2, pp. 297-307.

Osinubi, K. J. and Medubi, A. B. (1997b)."Effect of Lime and phosphatic waste admixture on tropical Black Clay." *Proceedings 4th Regional Conference on Geotechnical Engineering, GEOTROPIKA '97*, Johor Bahru, 11-12 November, Malaysia, pp. 257 – 272.

Osinubi, K. J**.** and Mustapha.A. M. (2005). 'Potentials of bagasse ash as a pozzolana.' *Proceedings of the 4th Nigerian Materials Congress "NIMACON 2005"*, Zaria, Nigeria, 17 – 19 November, pp. 41 -45.

Osinubi, K. J**.** and Stephen, T. A. (2005a). 'Economic utilization of an agro-industrial waste – bagasse ash.' *Proceedings of the 4th Nigerian Materials Congress "NIMACON 2005"*, Zaria, Nigeria, 17 –19 November, pp.36-40.

Osinubi, K. J. and Eberemu, A. O. (2006).'Effect of bagasse ash on the strength of stabilized lateritic soil.' *Book of Abstracts of the 5th Nigerian Materials Congress "NIMACON 2006"*, Abuja, Nigeria, 17 - 19 November. pp. 202 – 208.

Osinubi, K. J. and Stephen, T. A. (2006a). 'Effect of bagasse ash content on particle size distribution and plasticity characteristics of black cotton soil.' *Proceedings of the 5th Nigerian Materials Congress "NIMACON 2006"*, Abuja, Nigeria, 17-19 November. pp. 214 - 220.

Osinubi, K. J. and Stephen, T .A. (2006b). 'Effect of curing period on bagasse ash stabilized black cotton soil.' *Proc. of Bi-monthly Meetings/Workshops organized by the Zaria Chapter of Materials Society of Nigeria*, pp. 1 - 9.

Osinubi, K. J. and Stephen, T .A. (2007). 'Influence of compactive efforts on bagasse ash treated black cotton soil.' *Nigerian Journal of Soil and Environmental Research*, Vol. 7, pp. 92 – 101.

Osinubi, K. J., Eberemu, A. O. and Aliu, O. S. (2007a)..'Stabilization of laterite with cement and bagasse ash admixture.' Proceedings. of the *First Inter. Conf. on Environ. Res., Techn. and Policy "ERTEP 2007"*under the auspices of International Society of Environmental Geotechnology , Accra, Ghana, 16 - 19 July, Category B: Mining and Environment, pp. 1 - 14.

Osinubi, K. J**.,** Bafyau, V. and Eberemu, A. O. (2007b). 'Bagasse ash stabilization of lateritic soil.' Proc. of the *First Inter. Conf. on Environ. Res., Techn. and Policy "ERTEP 2007"* under the auspices of International Society of Environmental Geotechnology, Accra, Ghana, 16 -19 July, Category E: State-of-the-Art Technologies for Environmental Performance and Protection, pp.1 - 17.

Osinubi, K. J., Eberemu, A. O. and Simon, K. L. (2007c). 'Influence of Bagasse ash content and curing period on the permeability of lateritic soil compacted at reduced Proctor effort.' Proc. of Bi-monthly Meetings/Workshops organized by the Zaria Chapter of Materials Society of Nigeria, pp.17 -25. .

Osinubi, K. J. and Mustapha, A. M. (2008). 'Effect of compactive efforts on cement sugarcane bagasse ash – laterite mixture.' Submitted to *Nigerian Society of Engineers Technical Transactions*.(Accepted for publication March 2008)

Osinubi, K.J., Ijimdiya, T. S. and Nmadu, I. (2008a). 'Effect of compactive effort on lime treated black cotton soil using bagasse ash as admixture.' Book of Abstracts of the 2nd International Conference on Engineering Research & Development: Innovations (ICER&D 2008), Benin City, Nigeria, 15-17 April. Technical Session 9B – Construction and Structures, Paper ICERD08056, p. 216 - 217.

Osinubi, K.J., Ijimdiya, T. S. and Nmadu, I. (2008b). 'Lime stabilization of black cotton soil using bagasse ash as admixture.' Book of Abstracts of the 2nd International Conference on Engineering Research & Development: Innovations (ICER&D 2008), Benin City, Nigeria, 15-17 April. Technical Session 9B – Construction and Structures, Paper ICERD08058, p. 217

Osinubi, K. J., Bafyau, V. and Eberemu, A. O.(2008c). 'Bagasse ash stabilization of lateritic soil.' In:Appropriate Technologies for Environmental Production in the developing World. Edited by E. K. Yanful Springer, Netherlands.(To be published in 2008).

Peter, G.M (1993). "Fly ash stabilization of tropical Hawai soils." In: *Fly ash for soil improvement.* K. D Sharp (ed) Geotechnical Engineering Division of the ASCE, *Geotechnical Special Publications*,No.36,pp. 15-20.

Plait, R. M (1953)."Determination of swelling pressures of black cotton soil – A Method." *Proceedings of the Third International Conference on Soil Mechanics and Foundation Engineering*, Vo1.1, pp 170-172,Zurich,Switzerland,16th -27th August.

Portland Cement Association (1970). *Recommended Practice for construction of Residential Concrete Floors on Expansive soil*. Vo1. 2. Portland Cement Association, Los Angeles.

Rene, F.V. (1971). "Immediate Amelioration of wet cohesive soils by quicklime" *Transportation Road Research Journal*, Vo1. 501.

Robert, L. S. (1993). "Fly ash for use in the stabilization of industrial wastes." In: *Fly Ash for Soil Improvement*, K. D. Sharp (ed) Geotechnical Engineering Division of the ASCE, *Geotechnical Special Publications*, No. 36, pp. 58-72.

Sahel, N. A (1993). "Treatment of calcareous expansive clays." In: *Fly Ash for Soil Improvement. Geotechnical Special Publications* No. 36, K D. Sharp (ed) Geotechnical Engineering. Division of the ASCE, pp 100-115.

Saleh, M. and Utpal. D. (1993). “Stablilization of South Texas soils with fly ash”. In Fly Ash for Soil Improvement .”*Geotechnical Special Publications* No. 36. K. D. Sharp (ed) Geotechnical Engrg Division of the ASCE, pp. 30-35.

Sherwood, P.T (1957). “The stablilization with cement of weathered and sulphate-bearing clays” Geotechnique. Vo1.7, pp 179-191.

Skempton, A.M (1953) “*The colloidal activity of clays*”, Proc. 3rd int. conf. of Soil Mech. Foundation Engrg, Switzerland, Vo1.1 pp 57-61.

Smith, R. G (1992). “Alternatives to Ordinary Portland Cement.” *British Building Society Journal*, Vo1.25, pp. 1-17.

Stephen, A . T. (2005).*Stabilization Potential of Bagasse Ash on Black Cotton Soil. Un*published M.Sc thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Tomlinson, M.J (1999), *Foundation Design and Construction*. 6th Edition, Longman Harlow, Essex.

TRL (1993), *A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-tropical countries.* Transport Research Laboratory, Road Note 31, Crowthome,Berkshire, United Kingdom.

Warren, K.W and Kirby. T.M (2004). “Expansive clay soil- A- widespread and costly geohazard.*” Geostrata*. Geo-Institute of the American Society of Civil Engineers, Jan., pp. 24-28.

Yamanouchi, T (1975). ”Problems in the development of soil stablilization.”, *State and Municipal Record*, Vo1.68, No. 7, pp. 365-374.
Yoder, F. J and Witczak N. W (1975). Principles of Pavement Design. Wiley-Intercience Publication, New York. 711pp

APPENDIX A

Table 1 :Natural Moisture Content Test Result

Container No.	Container + Wet (g)	Container + Dry (g)	Empty Container (g)	Dry Weight (g)	Loss of moisture (g)	Moisture Content (%)
25	34.30	32.70	14.80	17.90	1.60	8.90
55	23.20	22.30	11.60	10.70	0.90	8.40
110	26.60	25.30	11.50	13.80	1.30	9.40
Average moisture content (%)						8.90

Table 2 :Test Result of Specific Gravity of the Soil Particles

Bottle No.	**1**	**2**	**3**
Wt. of bottle + water W4 (g)	48.50	49.70	48.30
Wt. of bottle + soil water W3(g)	55.88	58.96	59.04
Wt. of bottle + soil W2(g)	38.88	40.68	42.08
Wt. of bottle W1(g)	25.50	24.30	23.50
Wt. of Additional water (W4 – W1) (g)	23.00	25.40	24.80
Wt. of water added to soil (W3 – W2)(g)	17.00	18.28	16.96
Wt. of soil (W2 – W1) (g)	13.38	16.38	18.58
Wt of water displaced by soil	6.00	7.12	7.84

(W4 – W1) – (W3 – W2) = W(g) Specific gravity of the soil particles (W2 – W1)/ W	2.23	2.30	2.37
Average Specific gravity			**2.30**

Table 3: Test Result of Specific Gravity of Locust Bean Waste Ash

Bottle No.	**1**	**2**	**3**
Wt. of bottle + water W4(g)	48.50	49.60	50.00
Wt. of bottle + ash water W3(g)	50.70	52.50	55.80
Wt. of bottle + ash W2(g)	28.10	30.10	34.70
Wt. of bottle W1(g)	23.50	24.50	23.20
Wt. of Additional water (W4 – W1) (g)	25.00	25.10	26.80
Wt.of water added to ash (W3 – W2) (g)	22.60	22.40	21.10
Wt. of ash (W2 – W1) (g)	4.60	5.60	11.50
Wt of water displaced by ash (W4 – W1) – (W3 – W2) = W(g) Specific gravity of the ash particles (W2 – W1)/ W	2.40 1.92	5.60 2.07	5.70 2.02
Average Specific gravity			**2.00**

Table 4: Sieve Analysis Result for the Natural Soil (0 % LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	7.30	7.3	3.65	96.4
1.18	3.30	3.3	1.65	94.7
600µm	2.20	2.2	1.10	93.6
425µm	5.60	5.6	2.80	90.8
300µm	2.00	2.0	1.00	89.8
212µm	3.40	3.4	1.70	88.1
150µm	16.70	16.7	8.35	79.8
75µm	21.40	21.4	10.70	69.1

Table 5 : Sieve Analysis Result for the Stabilized Soil (2.5 %LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	7.20	7.2	3.60	96.4
1.18	3.80	3.8	1.90	94.5
600µm	2.40	2.4	1.20	93.3
425µm	6.00	6.0	3.00	90.3
300µm	1.40	1.4	0.70	89.6
212µm	4.40	4.4	2.20	87.4
150µm	16.40	16.4	8.20	79.2
75µm	21.00	21.0	10.50	68.7

Table 6 : Sieve Analysis Result for the Stabilized Soil (5.0 %LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	8.20	8.2	4.10	95.9
1.18	3.20	3.2	1.60	94.3
600µm	2.20	2.2	1.10	93.2
425µm	6.40	6.4	3.20	90.0
300µm	2.00	2.0	1.00	89.0
212µm	4.00	4.0	2.0	87.0
150µm	16.80	16.8	8.40	78.6
75µm	20.80	20.8	10.40	68.2

Table 7 : Sieve Analysis Result for the Stabilized Soil (7.5 %LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	8.00	8.0	4.00	96.9
1.18	3.60	3.6	1.80	94.2
600µm	2.60	2.6	1.30	92.9
425µm	6.20	6.2	3.10	89.8
300µm	1.80	1.8	0.90	88.9
212µm	4.40	4.4	2.20	86.7
150µm	16.80	16.8	8.40	78.3
75µm	20.80	20.8	10.40	67.9

Table 8 :Sieve Analysis Result for the Stabilized Soil (10 %LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	9.40	9.4	4.70	95.9
1.18	3.20	3.2	1.60	93.7
600µm	3.00	3.0	1.50	92.2
425µm	5.00	5.0	2.50	89.7
300µm	2.80	2.8	1.40	88.3
212µm	4.60	4.6	2.30	86.0
150µm	16.60	16.6	8.30	77.7
75µm	21.00	21.0	10.50	67.2

Table 9 :Sieve Analysis Result for the Stabilized Soil (12.5 %LBWA)

BS Sieve Size (mm)	Wt. Retained (g)	Wt. Retained (g)	Percent Retained	Percent Passing (%)
3.175	0	0	0	100
2.4	10.40	10.4	5.20	94.8
1.18	2.80	2.8	1.40	93.4
600µm	2.80	2.8	1.40	92.0
425µm	5.60	5.6	2.80	89.2
300µm	2.80	2.8	1.40	87.8
212µm	4.60	4.6	2.30	85.5
150µm	16.20	16.2	8.10	77.4
75µm	19.40	19.4	9.70	67.7

Table 10: Sieve Analysis Result for the Stabilized Soil (15 %LBWA)

BS Sieve Size (mm)	**Wt. Retained (g)**	**Wt. Retained (g)**	**Percent Retained**	**Percent Passing (%)**
3.175	0	0	0	100
2.4	10.80	10.8	5.40	94.6
1.18	2.60	2.6	1.30	93.3
600µm	2.80	2.8	1.40	91.9
425µm	5.80	5.8	2.90	89.0
300µm	2.80	2.8	1.40	87.6
212µm	4.60	4.6	2.30	85.3
150µm	16.00	16.0	8.00	77.3
75µm	19.40	19.4	9.70	67.6

Table 11: Result of Hydrometer Analysis for Natural Soil (0 % LBWA)

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9.12 am	2 min	68.0		5.70	67.8	0.0638	60.0
	4 min	64.7		6.28	64.5	0.0352	57.1
	8 min	59.9		7.13	59.7	0.0120	52.8
	15min	57.9		7.48	57.7	0.0112	51.1
	30min	49.2		9.01	49.0	0.0067	43.4
10.12am	1Hr	43.3		10.05	43.1	0.0038	38.1
11.12am	2Hrs	39.4		10.74	39.2	0.0020	34.7
1.12pm	4Hrs	35.8		11.37	35.6	0.0011	31.5
3.12pm	6Hrs	33.2		11.83	33.0	0.0007	29.2
9.12pm	12Hrs	31.2		12.18	31.0	0.0004	27.4

Table 12: Result of Hydrometer Analysis for 2.5 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table (F)	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9.34 am	2 min	65.5		6.14	65.3	0.0688	58.4
	4 min	61.7		6.81	61.5	0.0381	55.0
	8 min	58.1		7.44	57.9	0.0208	51.8
	15min	57.2		7.60	57.0	0.0114	51.0
	30min	47.1		9.38	46.9	0.0070	42.0
10.34am	1Hr	41.8		10.31	41.6	0.0039	37.2
11.34am	2Hrs	37.6		11.05	37.4	0.0021	33.5
1.34pm	4Hrs	33.7		11.74	33.5	0.0011	30.0
3.34pm	6Hrs	31.9		12.06	31.7	0.0008	28.4
9.34pm	12Hrs	30.1		12.37	29.9	0.0004	26.8

Table 13: Result of Hydrometer Analysis for 5 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9.20 am	2 min	62.8		6.62	62.6	0.0741	57.3
	4 min	59.8		7.15	59.6	0.0400	54.5
	8 min	53.8		8.20	53.6	0.0230	49.0
	15min	54.8		8.03	54.6	0.0120	50.0
	30min	45.0		9.75	44.8	0.0073	41.0
10.20am	1Hr	40.0		10.63	39.8	0.0040	36.4
11.20am	2Hrs	35.7		11.39	35.5	0.0021	32.5
1.20pm	4Hrs	32.8		11.90	32.6	0.0011	29.8
3.20pm	6Hrs	30.8		12.25	30.6	0.0008	28.0
9.20pm	12Hrs	29.2		12.53	29.0	0.0004	26.5

Table14: Result of Hydrometer Analysis for 7.5 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table (F)	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9. 02 am	2 min	61.5		6.85	61.3	0.0767	57.0
	4 min	57.7		7.51	57.5	0.0421	53.5
	8 min	52.2		8.48	52.0	0.0237	48.4
	15min	49.8		8.91	49.6	0.0133	46.1
	30min	43.3		10.05	43.1	0.0075	40.1
10.02am	1Hr	38.3		10.93	38.1	0.0041	35.4
11.02am	2Hrs	32.7		11.91	32.5	0.0022	30.2
1.02pm	4Hrs	30.4		12.32	30.2	0.0012	28.1
3.02pm	6Hrs	29.2		12.53	29.0	0.0008	27.0
9.02pm	12Hrs	28.2		12.71	28.0	0.0004	26.0

Table 15: Result of Hydrometer Analysis for 10 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table (F)	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9. 13 am	2 min	58.4		7.39	58.2	0.0828	55.0
	4 min	53.1		8.32	52.9	0.0466	50.0
	8 min	48.9		9.06	48.7	0.0254	46.0
	15min	48.0		9.22	47.8	0.0138	45.2
	30min	39.6		10.70	39.4	0.0080	37.2
10.13am	1Hr	35.1		11.49	34.9	0.0043	33.0
11.13am	2Hrs	29.2		12.53	29.0	0.0023	27.4
1.13pm	4Hrs	26.7		12.97	26.5	0.0012	25.0
3.13pm	6Hrs	25.8		13.13	25.6	0.0008	24.2
9.13pm	12Hrs	24.5		13.36	24.3	0.0004	23.0

Table 16: Result of Hydrometer Analysis for 12.5 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table (F)	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9. 40 am	2 min	56.2		7.78	56.0	0.0871	54.0
	4 min	51.5		8.61	51.3	0.0482	49.5
	8 min	47.5		9.31	47.3	0.0261	45.6
	15min	46.6		9.47	46.4	0.0141	44.8
	30min	37.7		11.03	37.5	0.0082	36.2
10.40am	1Hr	31.3		12.16	31.1	0.0045	30.0
11.40am	2Hrs	26.3		13.04	26.1	0.0024	25.2
1.40pm	4Hrs	25.8		13.13	25.6	0.0012	24.7
3.40pm	6Hrs	24.6		13.34	24.4	0.0008	23.5
9.40pm	12Hrs	23.4		13.55	23.2	0.0004	22.4

Table 17:Result of Hydrometer Analysis for 15 % LBWA Stabilized Soil

Day and Clock time	Total time in min.	Hydrometer Reading	Factor from Table (F)	Effective Depth (cm)	Corrected Hydrometer Reading (R)	Particle sizes (mm)	Percentage passing (%) Fines (p)
	10 sec	-	0.0448	-	-	-	-
	15 sec	-		-	-	-	-
	30 sec	-		-	-	-	-
	1 min	-		-	-	-	-
9. 58 am	2 min	51.2		8.66	51.0	0.0970	50.0
	4 min	44.6		9.82	44.4	0.0550	43.5
	8 min	41.0		10.45	40.8	0.0293	40.0
	15min	40.8		10.49	31.6	0.0157	39.8
	30min	31.8		12.-07	25.5	0.0090	31.0
10.58am	1Hr	25.7		13.15	24.5	0.0049	25.0
11.58am	2Hrs	24.7		13.32	23.5	0.0025	24.0
1.58pm	4Hrs	23.7		13.50	22.8	0.0013	23.0
3.58pm	6Hrs	23.0		13.62	20.2	0.0009	22.4
9.58pm	12Hrs	20.4		14.08	18.4	0.0004	19.8

Table 18: Effect of Locust Bean Waste Ash on the Atterberg Limits of Black Cotton Soil.

Locust Bean Waste Ash Content (%)	Liquid Limit, LL (%)	Plastic limit, PL (%)	Plasticity index, PI (%)	Linear Shrinkage (%)
0	50.4	17.1	33.3	15.7
2.5	51.2	15.7	35.5	14.5
5.0	55.2	13.1	42.1	13.0
7.5	57.3	12.5	44.8	12.0
10	60.5	11.6	48.9	11.7
12.5	58.2	13.5	44.7	12.2
15	59.0	12.1	46.9	10.4

Table 19: Effect of Locust Bean Waste Ash Content on pH of Treated Soil

Locust Bean Waste ash content (%)	pH
0	8.3
2.5	8.6
5	8.7
7.5	9.0
10	9.2
12.5	9.7
15	10.0

Table 20: Effect of Locust Bean Waste Ash on the Swelling Pressures of Black Cotton Soil.

Locust Bean Waste Ash Content (%)	0	2.5	5	7.5	10	12.5	15
Swelling Pressure (kN/m^2)	42.60	38.80	37.90	32.20	33.20	21.30	20.90

Table 21: Effect of Locust Bean Waste Ash on the Maximum Dry Density of Black Cotton Soil

Locust Bean Waste Ash Content,%	Maximum Dry Density, Mg/m^3		
	BSL	WAS	BSH
0	1.59	1.68	1.83
2.5	1.63	1.76	1.86
5	1.70	1.75	1.81
7.5	1.67	1.72	1.80
10	1.65	1.70	1.80
12.5	1.71	1.73	1.82
15	1.56	1.68	1.73

Table 22: Effect of Locust Bean Waste Ash on Optimum Moisture Content

Locust Bean Waste Ash Content, (%)	Optimum Moisture content, %		
	BSL	WAS	BSH
0	18.53	16.83	14.00
2.5	18.10	16.20	13.70
5	17.70	16.60	14.20
7.5	18.30	16.80	14.20
10	18.70	18.00	14.90
12.5	17.80	17.64	14.30
15	18.9	18.10	14.80

Table 23: Effect of Locust Bean Waste Ash Content on UCS (BSL Compactive Effort)

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2			
	7 days curing	**7 days curing + 7 days soaking**	**14 days curing**	**28 days curing**
0	114.65	20.00	141.40	211.70
2.5	179.85	24.89	200.15	332.60
5	284.70	29.96	299.50	400.10
7.5	321.00	39.87	334.96	424.86
10	260.88	34.77	300.15	389.98
12.5	336.00	40.50	350.40	418.50
15	279.00	39.07	290.00	385.45

Table 24: Effect of Locust Bean Waste Ash Content on UCS (WAS Compactive Effort)

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2			
	7 days curing	7 days curing + 7 days soaking	14 days curing	28 days curing
0	299.96	22.40	310.30	389.75
2.5	345.16	27.50	375.50	430.40
5	299.40	30.75	308.45	435.60
7.5	325.15	40.60	349.00	457.44
10	290.05	40.45	326.00	390.54
12.5	349.10	45.56	365.45	430.35
15	324.50	40.05	335.00	405.40

Table 25 : Effect of Locust Bean Waste Ash Content (BSH Compactive Effort)

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2			
	7 days curing	**7 days curing + 7 days soaking**	**14 days curing**	**28 days curing**
0	401.5	30	435.58	562.80
2.5	438.54	33.70	470.47	607.70
5	400.54	35.95	440.10	629.60
7.5	384.50	44.00	455.25	565.89
10	449.55	50.90	465.38	560.28
12.5	399.98	54.45	415.37	514.14
15	425.52	40.75	431.17	525.35

Table 26 : Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (7 day UCS)

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2		
	BSL	WAS	BSH
0	114.65	299.96	401.50
2.5	179.85	345.16	438.54
5	284.70	299.40	400.54
7.5	321.00	325.15	384.50
10	260.88	290.05	449.55
12.5	336.00	349.10	399.98
15	279.00	324.50	425.52

Table 27: Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (14 day UCS).

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2		
	BSL	WAS	BSH
0	141.40	310.30	435.58
2.5	200.15	375.50	470.47
5	299.50	308.45	440.10
7.5	334.96	349.00	455.25
10	300.15	326.00	465.38
12.5	350.40	365.45	415.37
15	290.00	335.00	431.17

Table 28: Effect of Compactive Effort on Locust Bean Waste Ash Treated Black Cotton Soil (28 day UCS).

Locust Bean Waste Ash Content, (%)	Unconfined Compressive Strength, kN/m^2		
	BSL	WAS	BSH
0	211.70	389.75	562.80
2.5	332.60	430.40	607.70
5	400.10	435.60	629.60
7.5	424.86	457.44	565.89
10	389.98	390.54	560.20
12.5	418.50	430.35	514.14
15	385.45	405.40	525.35

Table 29: Effect of Curing Period on UCS

Compactive Effort	Unconfined Compressive Strength, kN/m^2		
	7 days	14 days	28 days
BSL	336.00	350.40	424.86
WAS	349.10	375.50	457.44
BSH	449.55	470.47	629.60

Table 30: Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (BSL compaction)

Locust Bean Waste Ash Content (%)	Unconfined Compressive Strength, kN/m^2		Resistance to loss in strength, R (%)
	7 days(curing) + 7 days (soaking), P	14 days (Curing) U	
0	20	141	14.2
2.5	25	200	12.5
5	30	300	10.0
7.5	40	335	11.9
10	35	300	11.7
12.5	41	350	11.7
15	39	279	14

Table 31: Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (WAS compaction)

Locust Bean Waste Ash Content (%)	Unconfined Compressive Strength, kN/m^2		Resistance to loss in strength, R (%)
	7 days(curing) + 7 days (soaking), P	14 days (curing), U	
0	22	310	7.1
2.5	28	376	7.4
5	31	291	10.7
7.5	41	349	11.7
10	40	326	12.3
12.5	46	335	13.7
15	41	335	12.2

Table 32 :Effect of Immersion in Water on UCS of Locust Bean Waste Ash Stabilized Black Cotton Soil (BSH compaction)

Locust Bean Ash Content (%)	Unconfined Compressive Strength, kN/m^2		R (%)
	7 days (curing) + 7 days (soaking), P	14 days (curing), U	
0	30	436	7.0
2.5	34	470	7.2
5	36	440	8.2
7.5	44	455	9.7
10	51	465	11.0
12.5	54	415	13.0
15	41	431	9.5

Table 33: Effect of Locust Bean Waste Ash Content on CBR (Unsoaked)

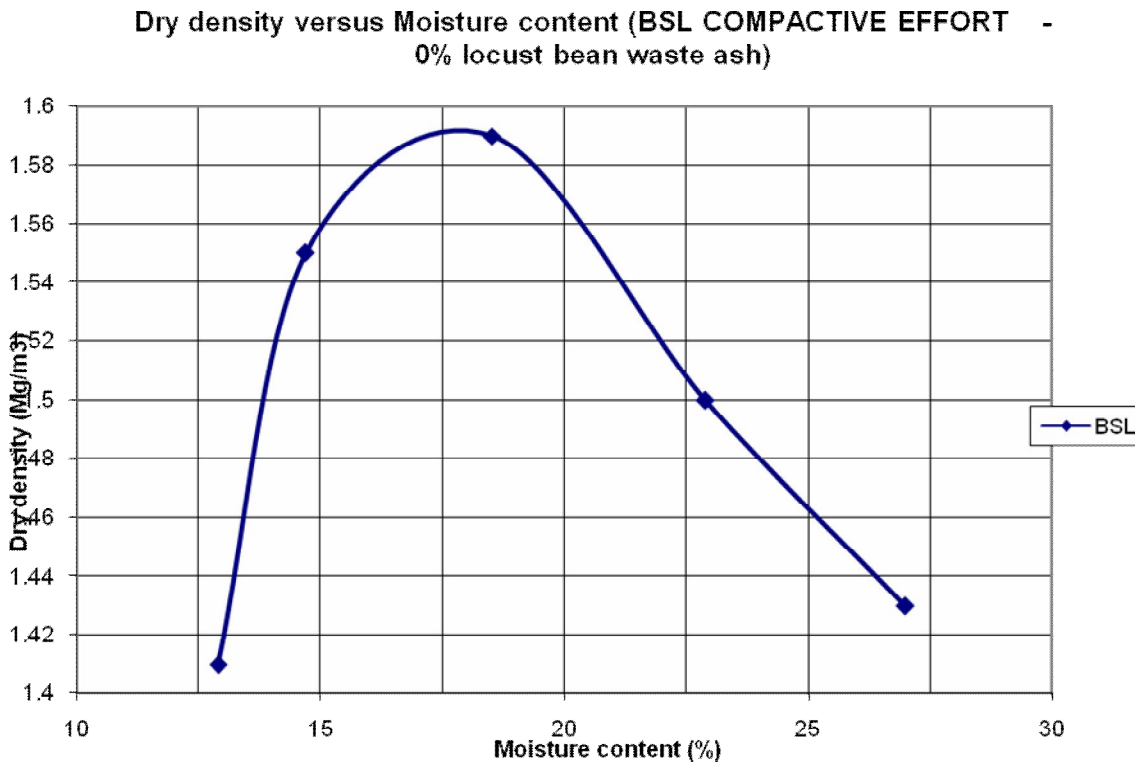
Locust Bean Waste Ash Content (%)	CBR (%)		
	BSL	WAS	BSH
0	4	6	8
2.5	5	6	9
5	7	8	9
7.5	8	9	10
10	8	12	12
12.5	11	11	12
15	10	11	11

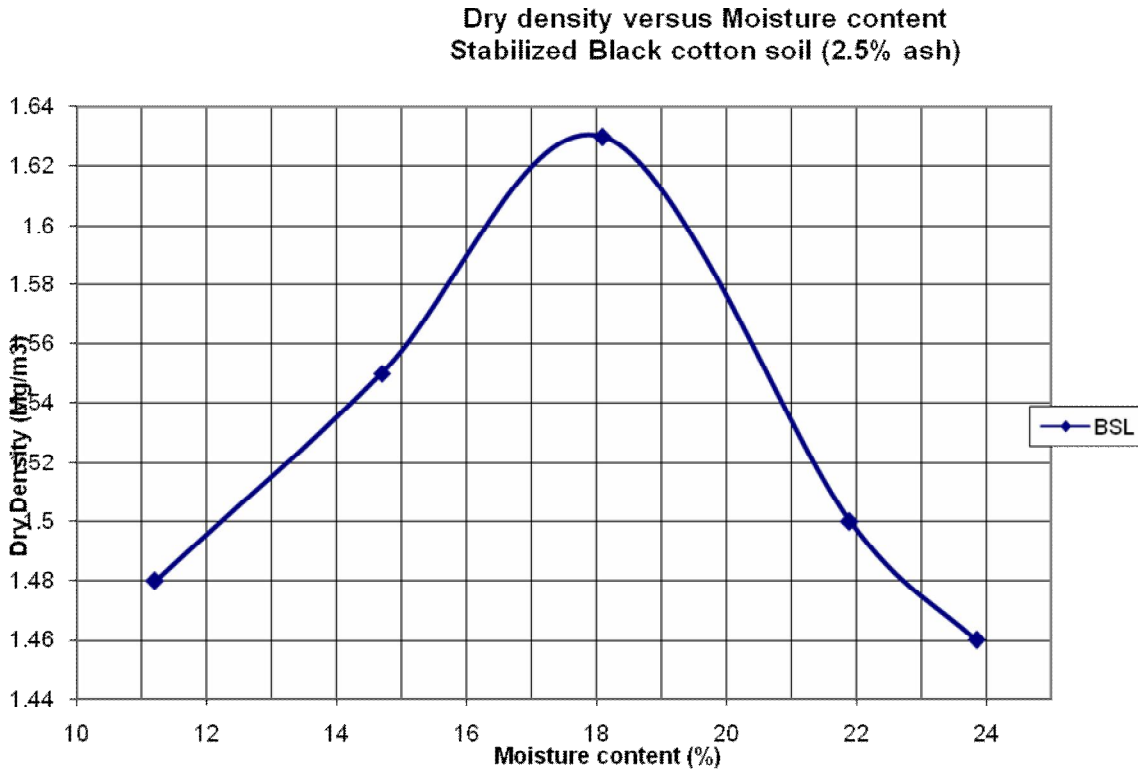
Table 34: Effect of Locust Bean Waste Ash Content on CBR (24 hours soaking)

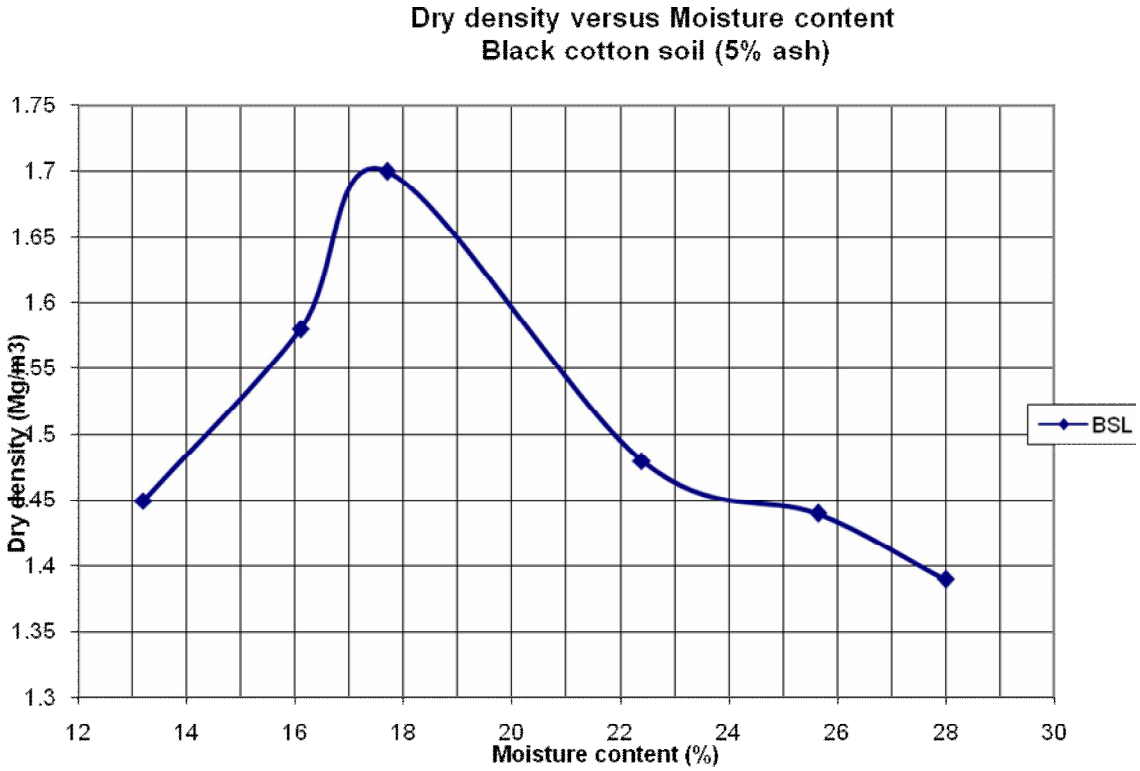
Locust Bean Waste Ash Content (%)	CBR (%)		
	BSL	WAS	BSH
0	3	6	7
2.5	3	6	8
5	5	7	9
7.5	6	8	10
10	5	7	10
12.5	6	8	9
15	6	8	10

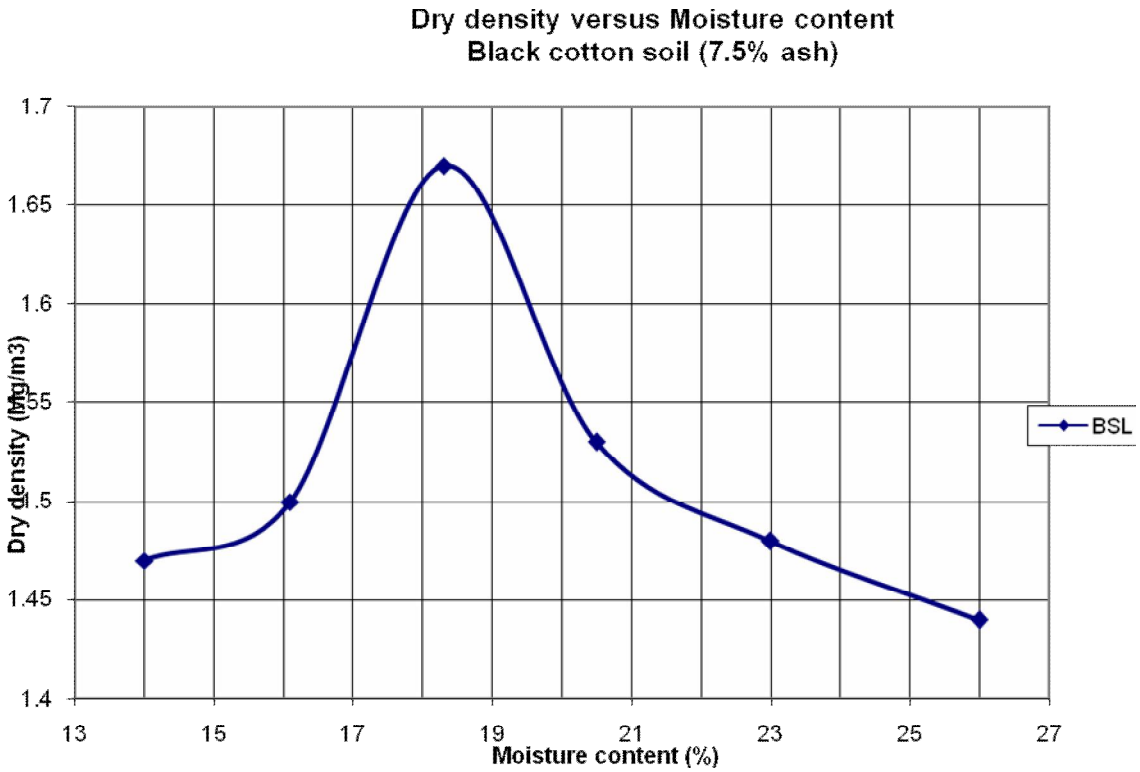
APPENDIX B

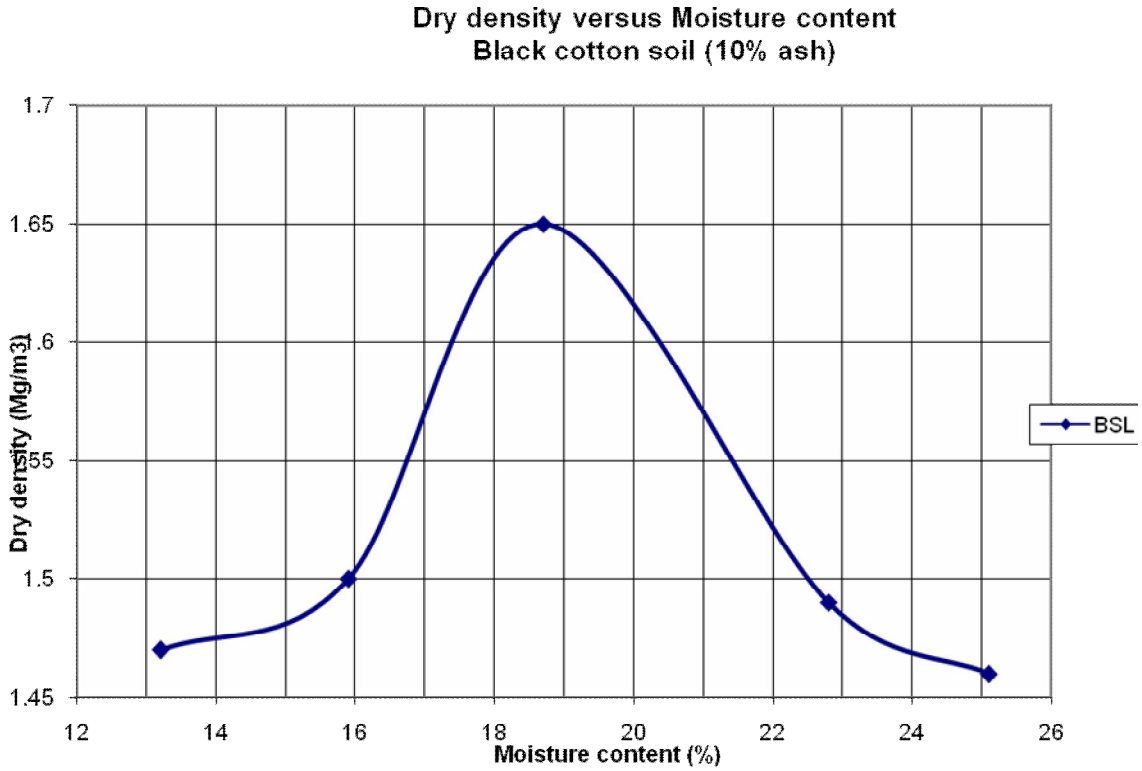
DRY DENSITY VERSUS MOISTURE CONTENT CURVES FOR BRITISH STANDARD LIGHT (BSL) COMPACTIVE EFFORT (0 -15% LBWA)

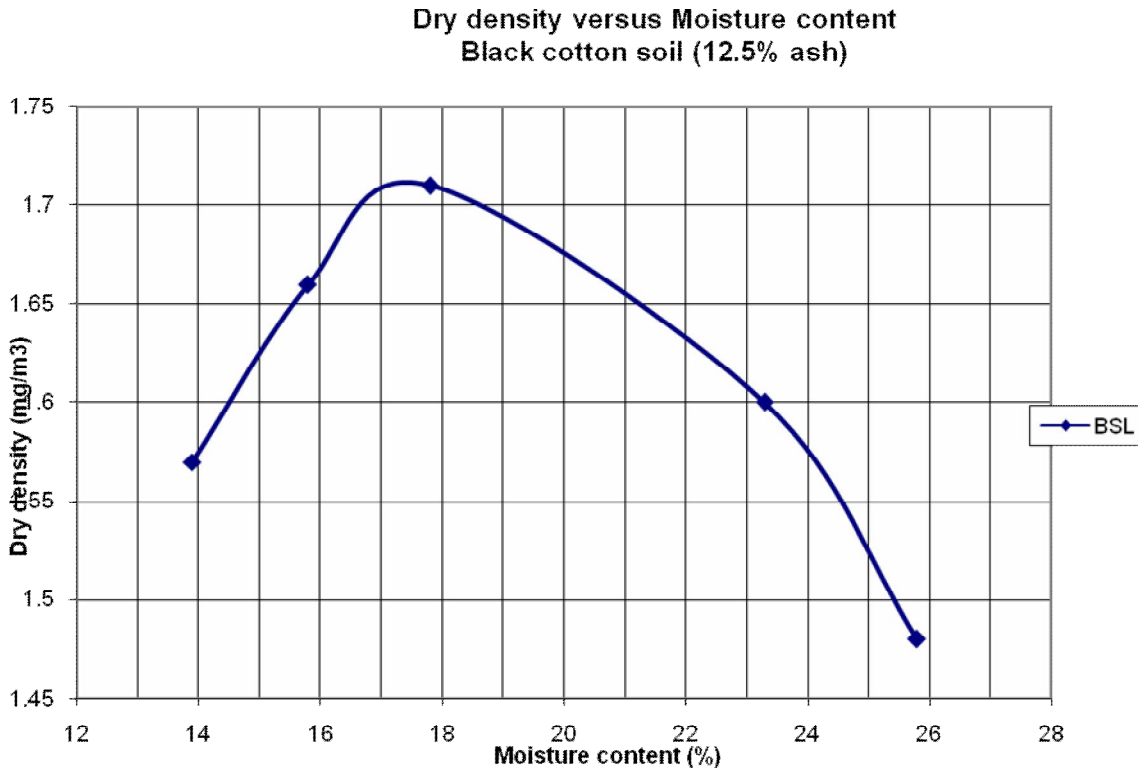

Dry density versus Moisture content (BSL COMPACTIVE EFFORT - 0% locust bean waste ash)
1.6
1.58
1.56
1.54
1.52
1.5
1.48
1.46
1.44
1.42
1.4
Dry density (Mg/m3)
10
15
20
25
30
Moisture content (%)
BSL

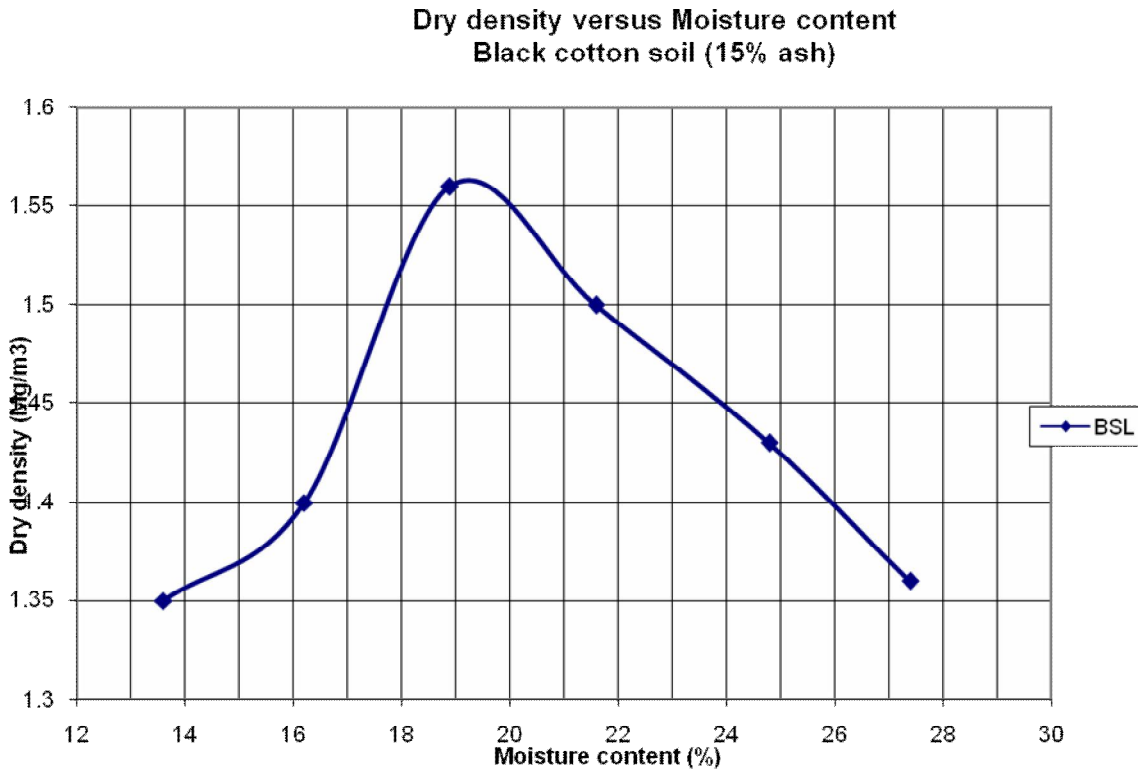

Dry density versus Moisture content
Stabilized Black cotton soil (2.5% ash)
1.64
1.62
1.6
1.58
1.56
1.54
1.52
1.5
1.48
1.46
1.44
Dry Density (Mg/m3)
10
12
14
16
18
20
22
24
Moisture content (%)
BSL


Dry density versus Moisture content
Black cotton soil (5% ash)
Dry density (Mg/m3)
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
12
14
16
18
20
22
24
26
28
30
Moisture content (%)
BSL

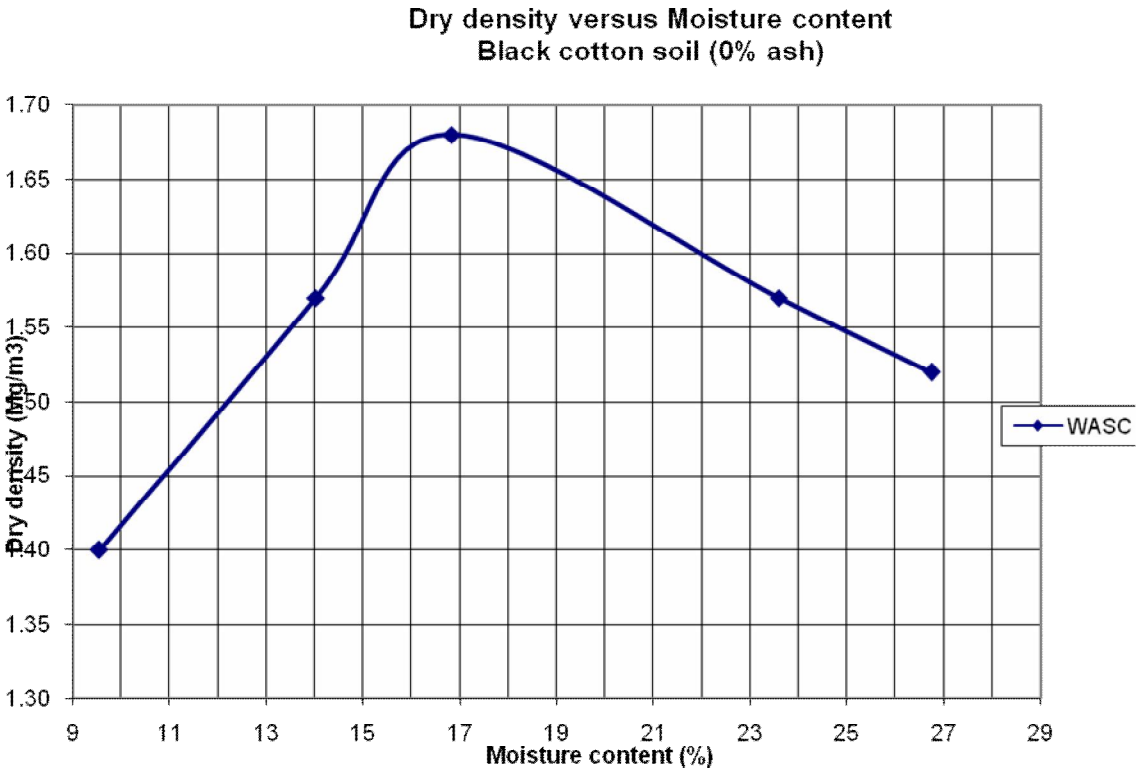

Dry density versus Moisture content
Black cotton soil (7.5% ash)
Dry density (Mg/m3)
1.7
1.65
1.6
1.55
1.5
1.45
1.4
13
15
17
19
21
23
25
27
Moisture content (%)
BSL

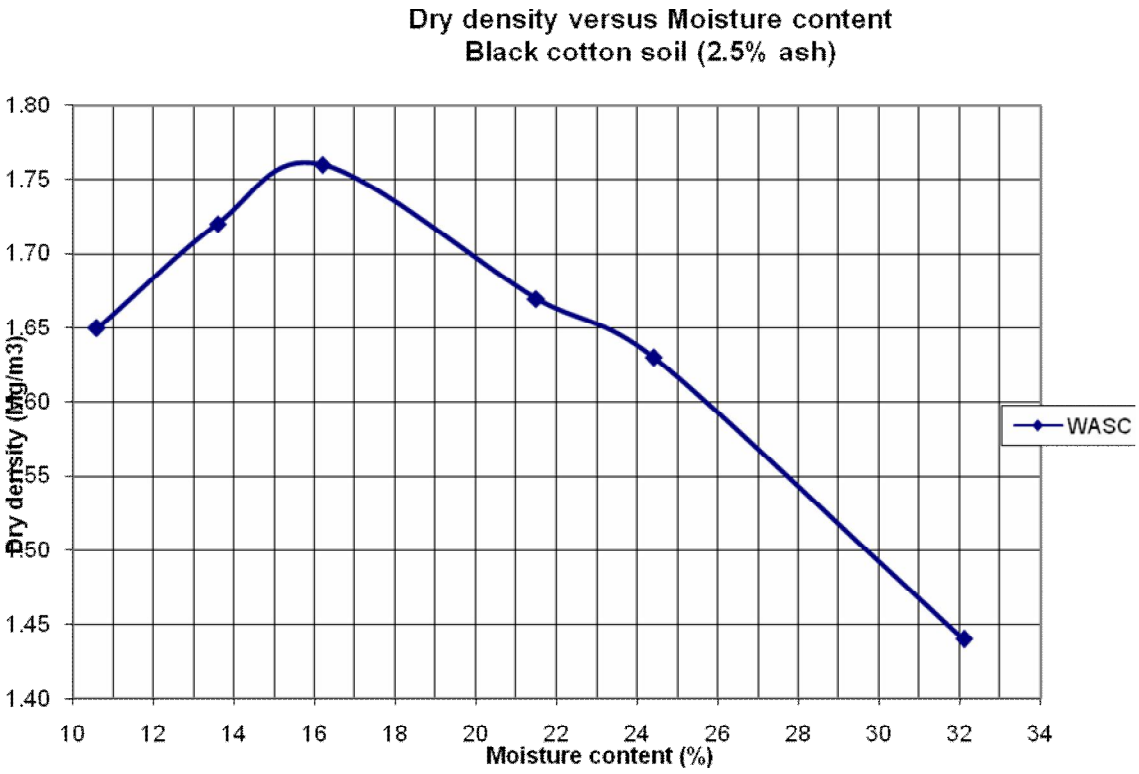

Dry density versus Moisture content
Black cotton soil (10% ash)
Dry density (Mg/m3)
1.7
1.65
1.6
1.55
1.5
1.45
12
14
16
18
20
22
24
26
Moisture content (%)
BSL

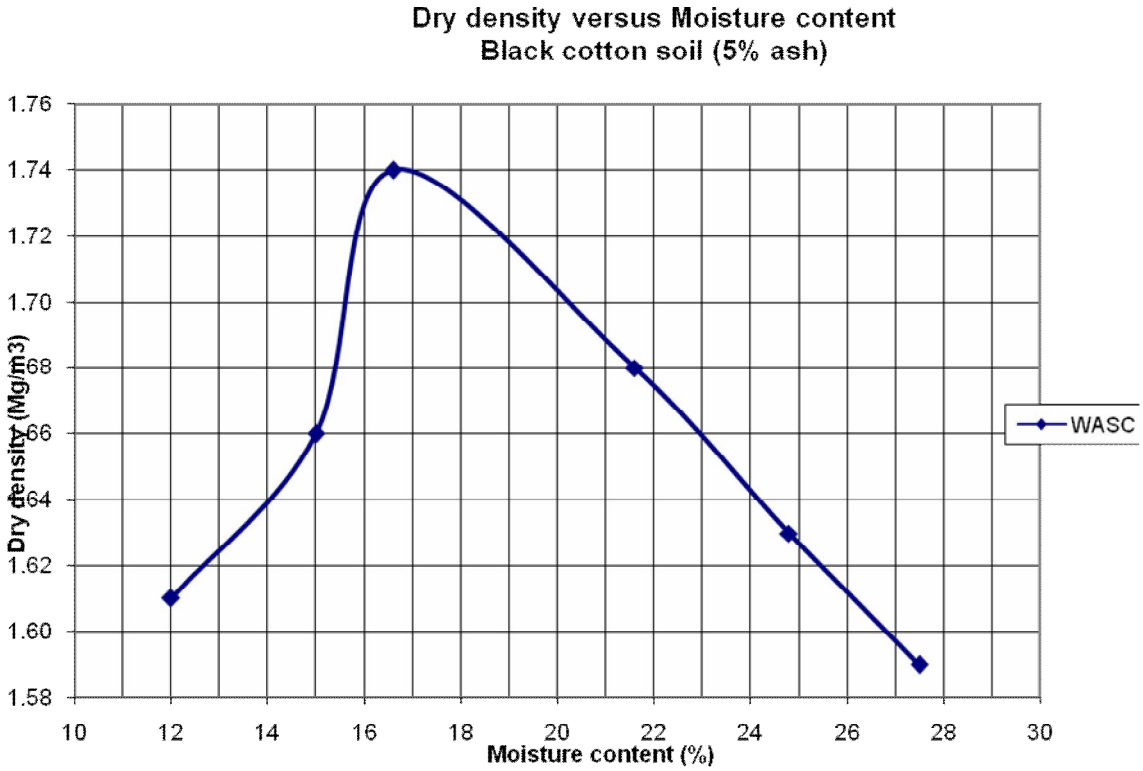

Dry density versus Moisture content
Black cotton soil (12.5% ash)
Dry density (mg/m3)
1.75
1.7
1.65
1.6
1.55
1.5
1.45
12
14
16
18
20
22
24
26
28
Moisture content (%)
BSL

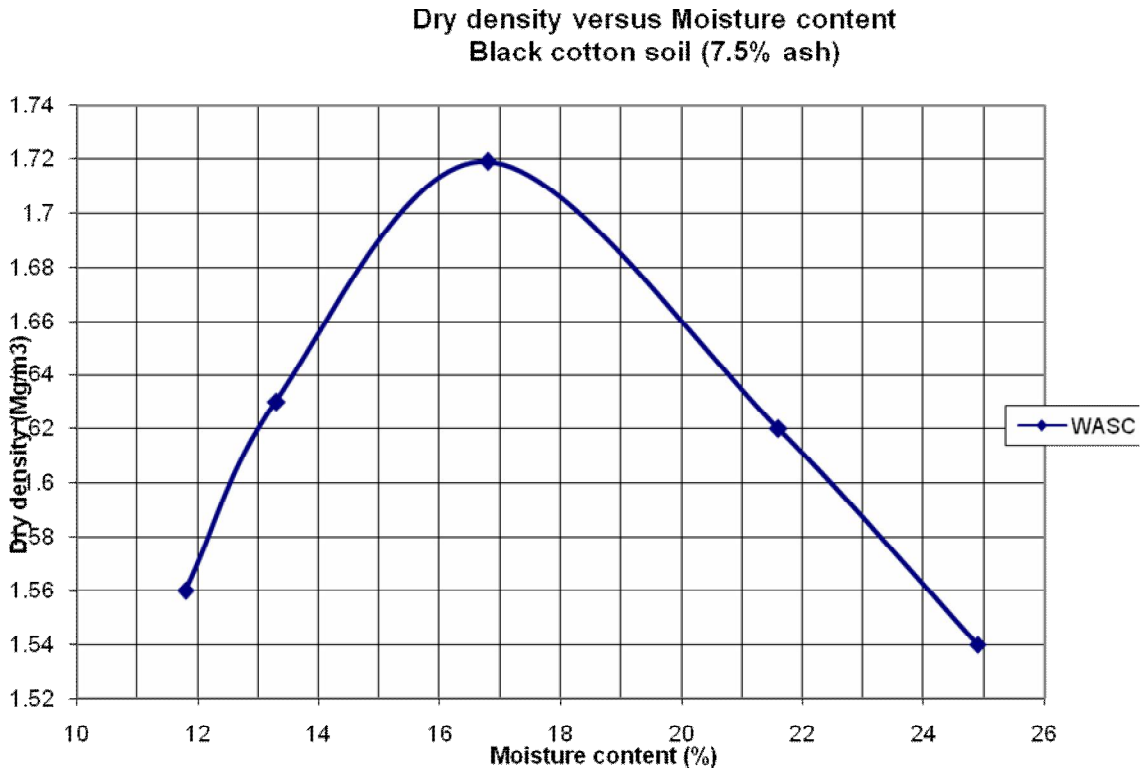

Dry density versus Moisture content
Black cotton soil (15% ash)
1.6
1.55
1.5
1.45
1.4
1.35
1.3
Dry density (Mg/m3)
12
14
16
18
20
22
24
26
28
30
Moisture content (%)
BSL

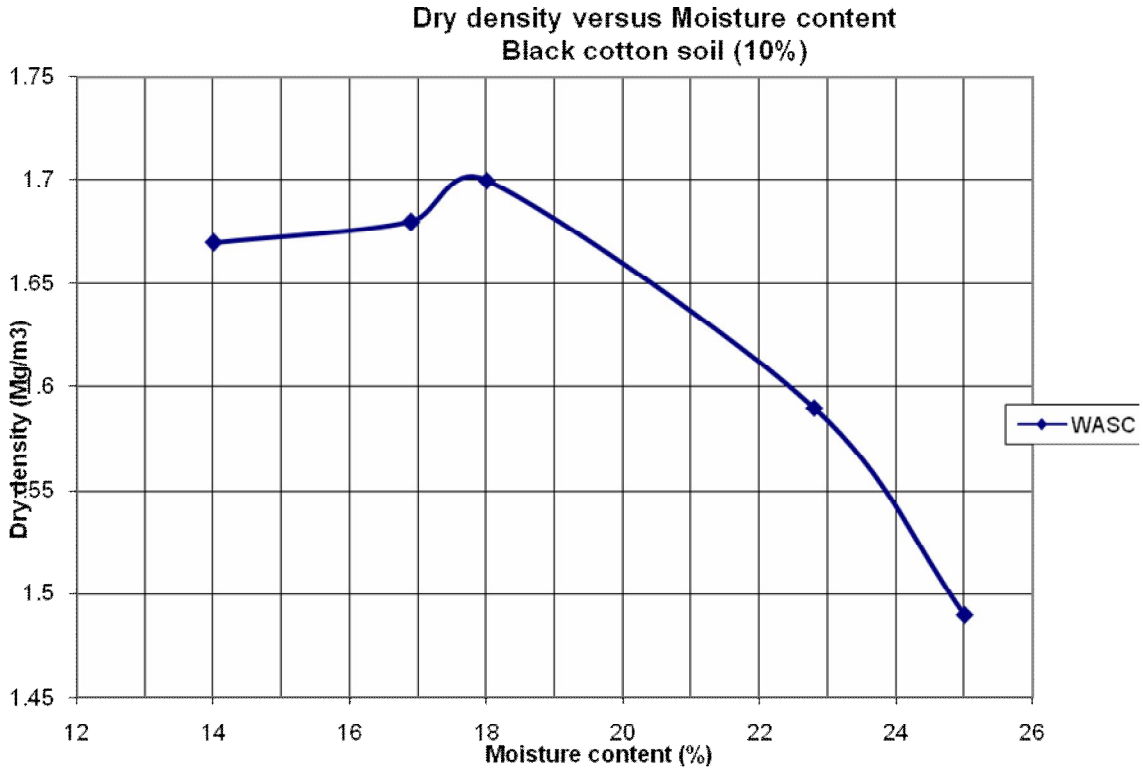
DRY DENSITY VERSUS MOISTURE CONTENT CURVES FOR WEST AFRICAN STANDARD (WAS) COMPACTIVE EFFORT (0 -15% LBWA)

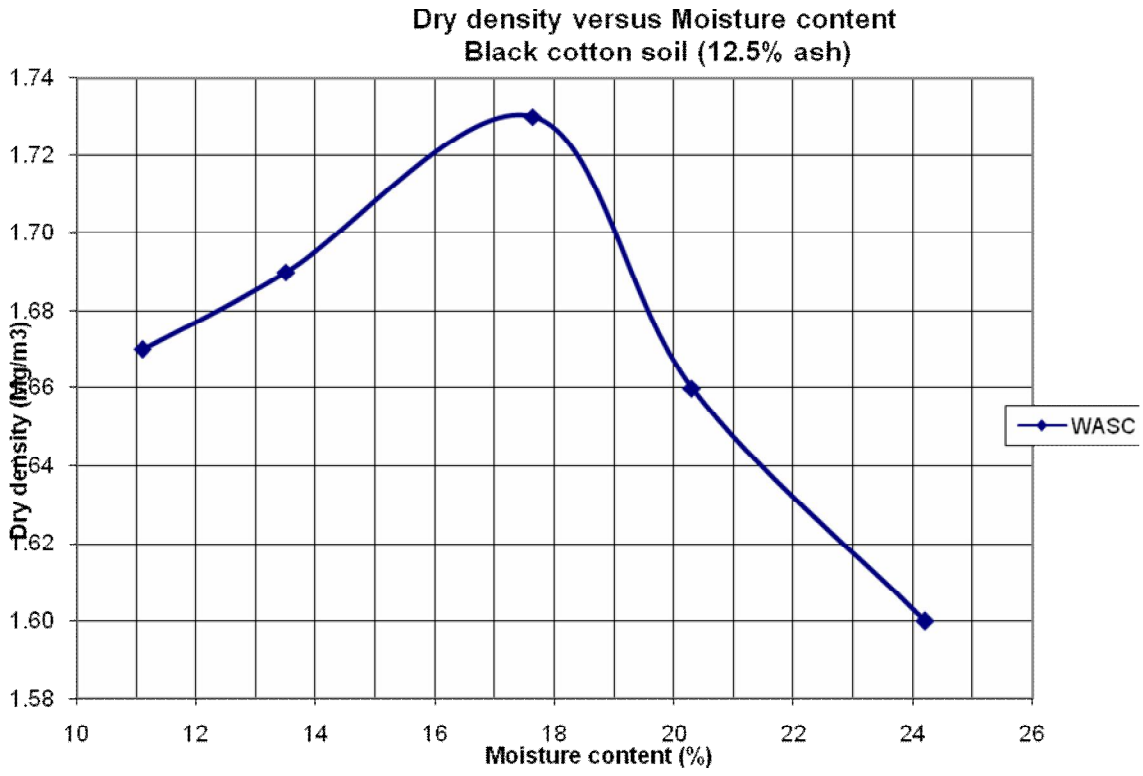

Dry density versus Moisture content
Black cotton soil (0% ash)
Dry density (kg/m3)
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
9
11
13
15
17
19
21
23
25
27
29
Moisture content (%)
WASC

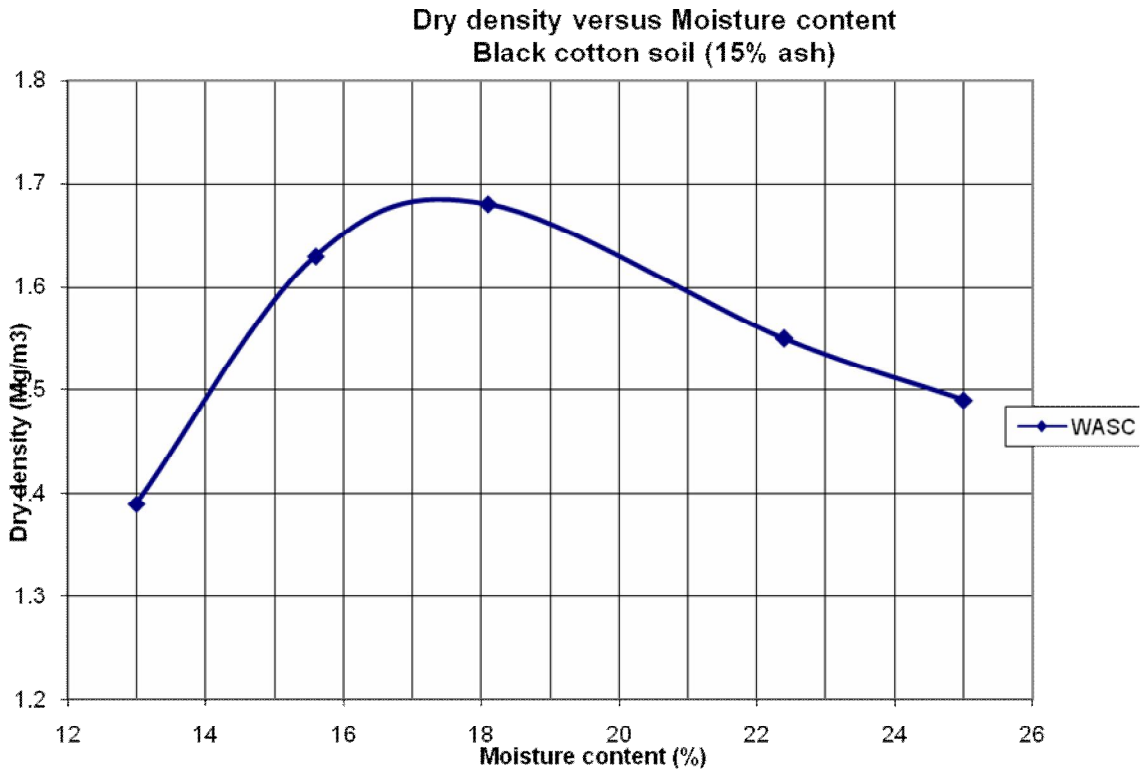

Dry density versus Moisture content
Black cotton soil (2.5% ash)
Dry density (kg/m3)
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
10
12
14
16
18
20
22
24
26
28
30
32
34
Moisture content (%)
WASC


Dry density versus Moisture content
Black cotton soil (5% ash)
Dry density (Mg/m3)
1.76
1.74
1.72
1.70
1.68
1.66
1.64
1.62
1.60
1.58
10
12
14
16
18
20
22
24
26
28
30
Moisture content (%)
WASC

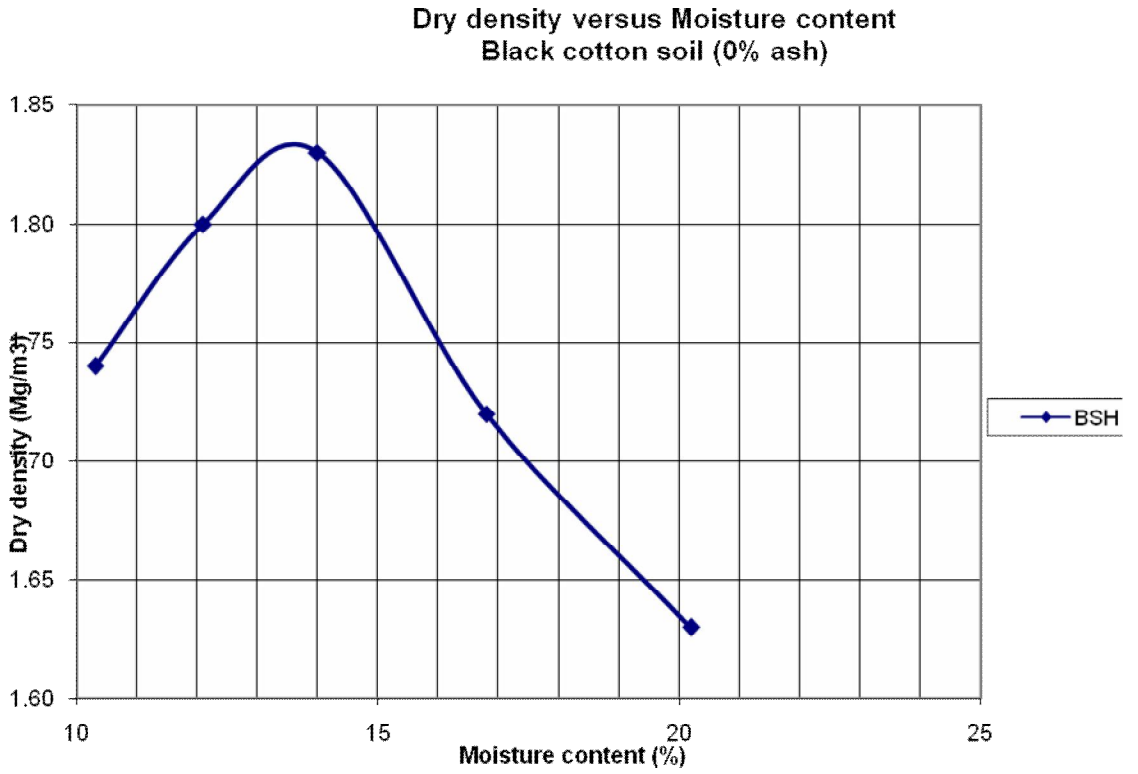

Dry density versus Moisture content
Black cotton soil (7.5% ash)
Dry density (Mg/m3)
1.74
1.72
1.7
1.68
1.66
1.64
1.62
1.6
1.58
1.56
1.54
1.52
10
12
14
16
18
20
22
24
26
Moisture content (%)
WASC

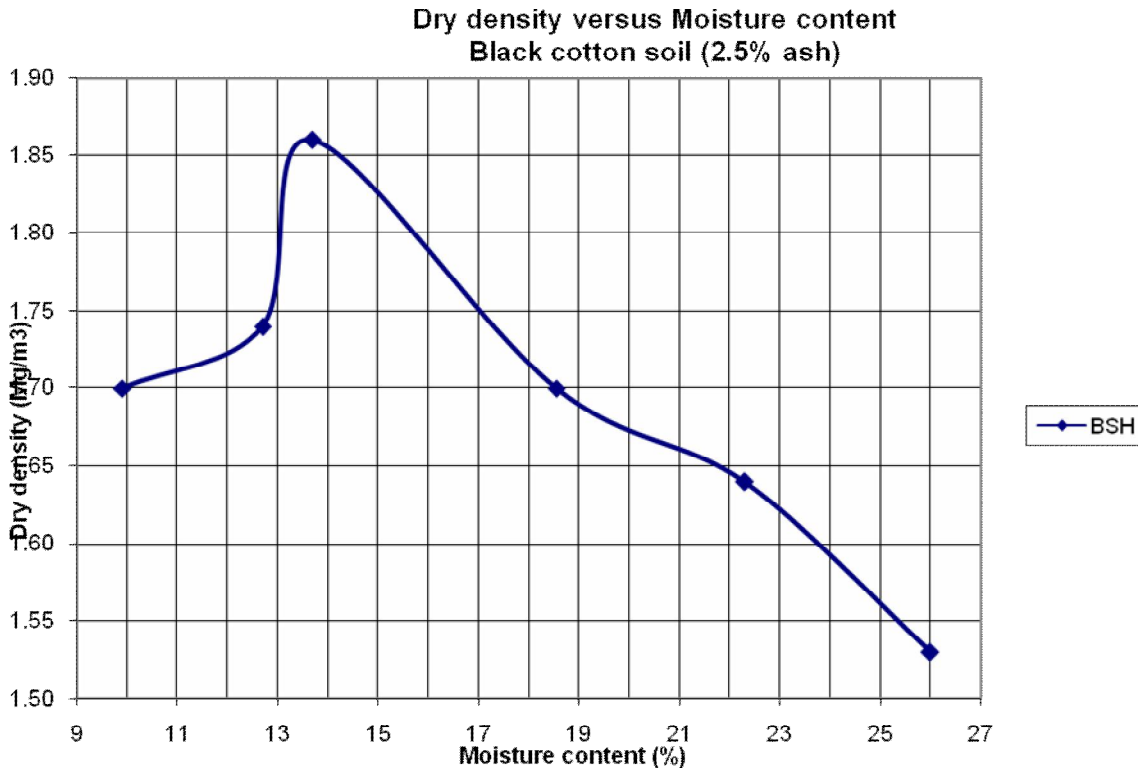

Dry density versus Moisture content
Black cotton soil (10%)
1.75
1.7
1.65
1.6
1.55
1.5
1.45
Dry density (Mg/m3)
12
14
16
18
20
22
24
26
Moisture content (%)
WASC

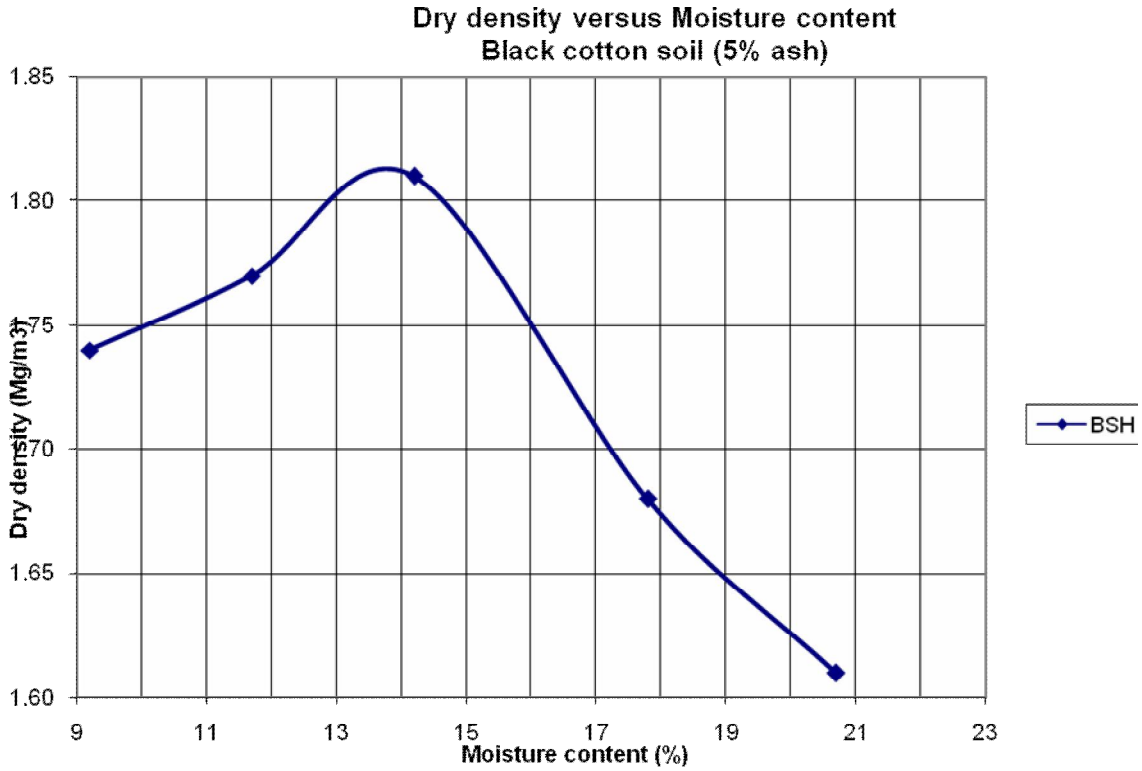

Dry density versus Moisture content
Black cotton soil (12.5% ash)
1.74
1.72
1.70
1.68
1.66
1.64
1.62
1.60
1.58
Dry density (Mg/m3)
10
12
14
16
18
20
22
24
26
Moisture content (%)
WASC

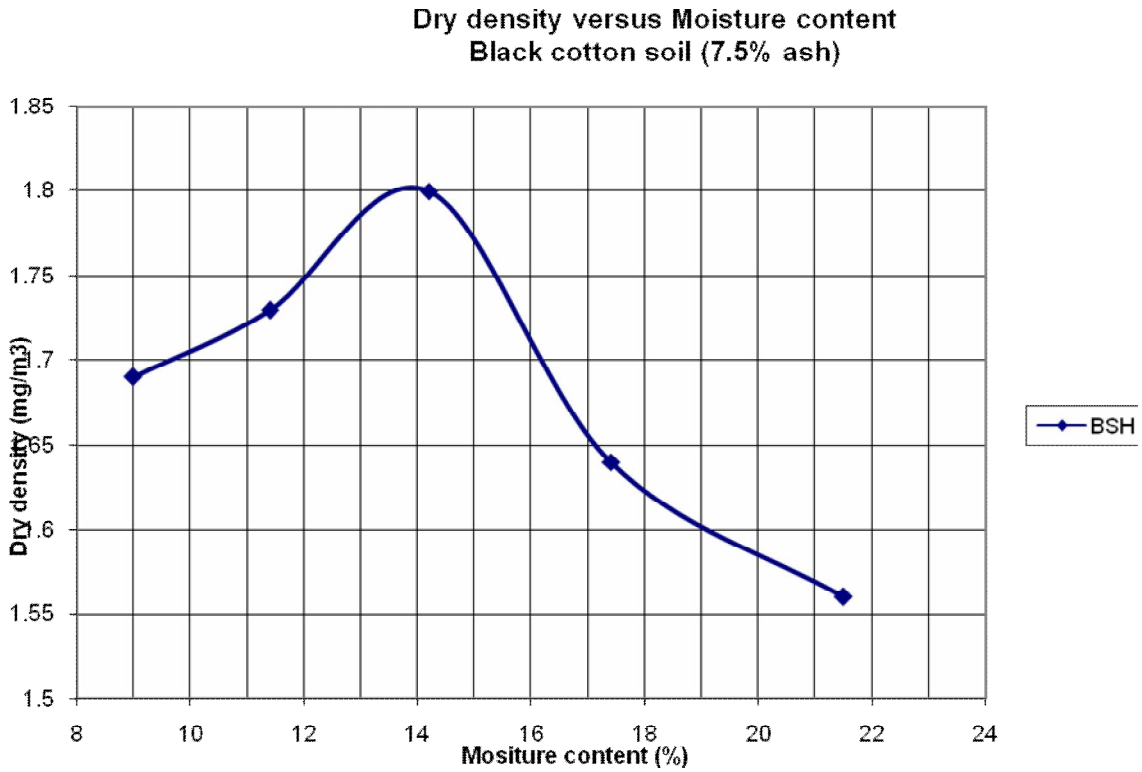

Dry density versus Moisture content
Black cotton soil (15% ash)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Dry density (Mg/m3)
12
14
16
18
20
22
24
26
Moisture content (%)
WASC

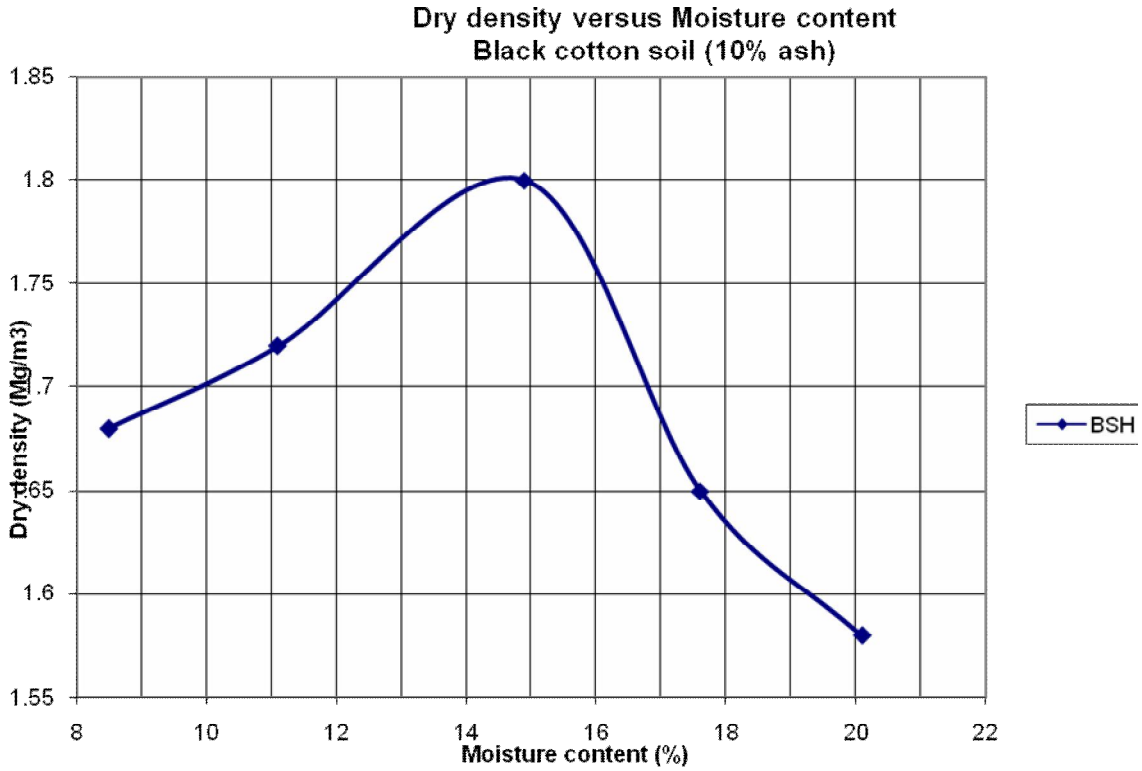
DRY DENSITY VERSUS MOISTURE CONTENT CURVES FOR BRITISH STANDARD HEAVY (BSH) COMPACTIVE EFFORT (0 -15% LBWA)

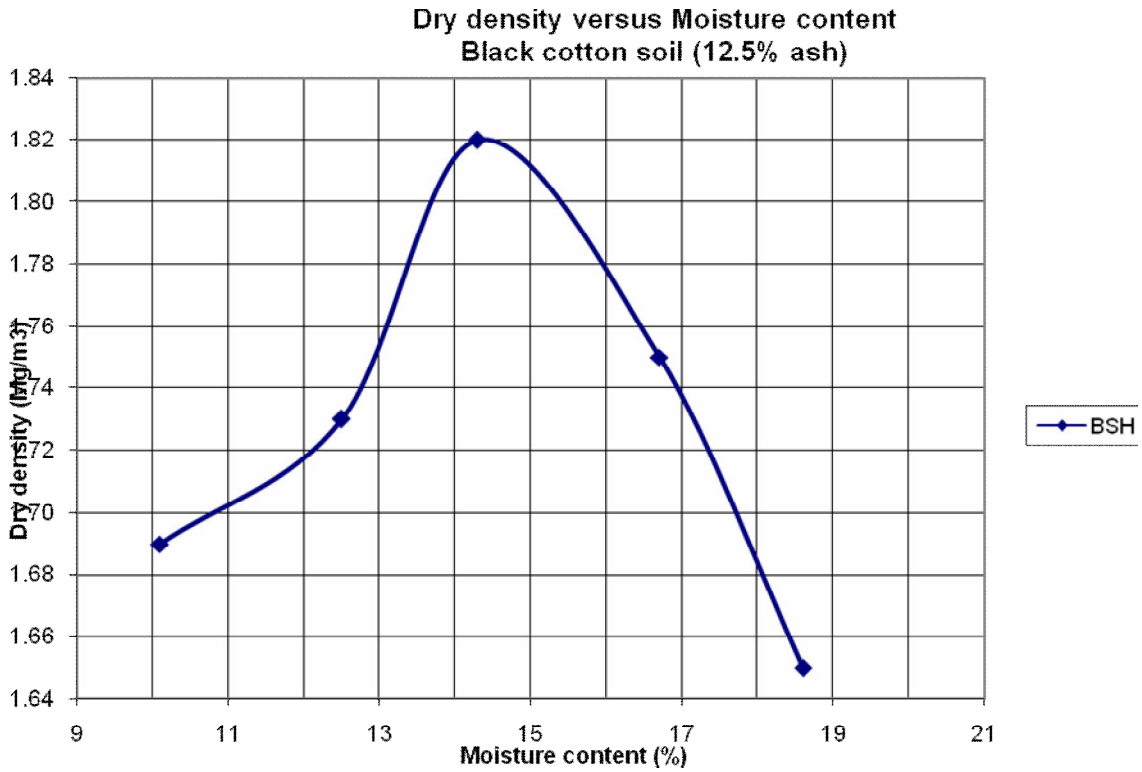

Dry density versus Moisture content
Black cotton soil (0% ash)
1.85
1.80
1.75
1.70
1.65
1.60
Dry density (Mg/m3)
10
15
20
25
Moisture content (%)
BSH

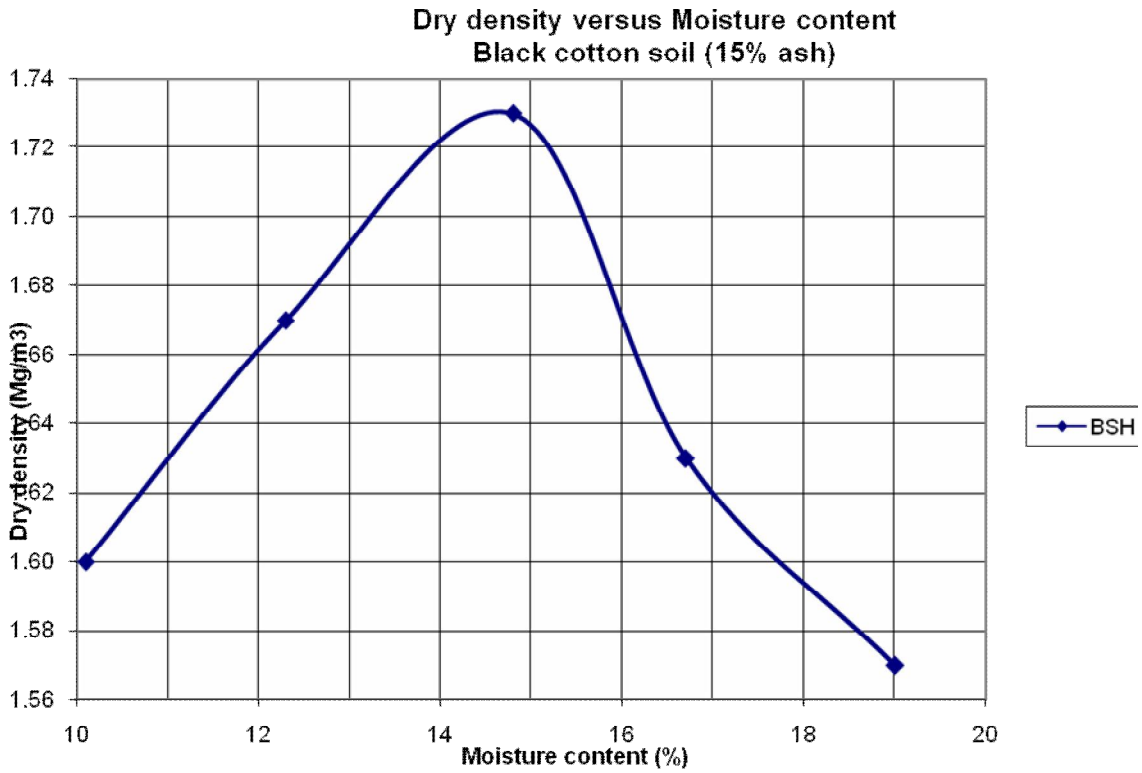

Dry density versus Moisture content
Black cotton soil (2.5% ash)
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
Dry density (Mg/m3)
9
11
13
15
17
19
21
23
25
27
Moisture content (%)
BSH


Dry density versus Moisture content
Black cotton soil (5% ash)
1.85
1.80
1.75
1.70
1.65
1.60
Dry density (Mg/m3)
9
11
13
15
17
19
21
23
Moisture content (%)
BSH


Dry density versus Moisture content
Black cotton soil (7.5% ash)
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
Dry density (mg/m3)
8
10
12
14
16
18
20
22
24
Mositure content (%)
BSH


Dry density versus Moisture content
Black cotton soil (10% ash)
1.85
1.8
1.75
1.7
1.65
1.6
1.55
Dry density (Mg/m3)
8
10
12
14
16
18
20
22
Moisture content (%)
BSH


Dry density versus Moisture content
Black cotton soil (12.5% ash)
1.84
1.82
1.80
1.78
1.76
1.74
1.72
1.70
1.68
1.66
1.64
Dry density (Mg/m3)
9
11
13
15
17
19
21
Moisture content (%)
BSH


Dry density versus Moisture content
Black cotton soil (15% ash)
Dry density (Mg/m3)
1.74
1.72
1.70
1.68
1.66
1.64
1.62
1.60
1.58
1.56
10
12
14
16
18
20
Moisture content (%)
BSH